MODSIM 2013

20th International Congress on Modelling and Simulation

22nd National Conference of the Australian Society for Operations Research — ASOR 2013
DSTO led Defence Operations Research Symposium — DORS 2013

ABSTRACTS

Adapting to change: the multiple roles of modelling

1–6 December 2013 ADELAIDE, Australia

EDITORS
Piantadosi, J., Anderssen, R.S. and Boland, J.

Modelling & Simulation Society of Australia & New Zealand Inc.

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Defence Operations Research Symposium
DORS
Adelaide, SA
December 2-5 2013

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About the Modelling and Simulation Society of Australia and New Zealand

The Modelling and Simulation Society of Australia and New Zealand Inc. has been active since 1974, and has run the previous 19 MODSIM Congresses in Australasia.

The society represents modellers and managers with interests in using quantitative and qualitative methods to manage practical problems in industry, environment, science, societal and economics areas. It is affiliated with the International Association for Mathematics and Computers in Simulation. **www.mssanz.org.au**

About the Australian Society for Operations Research

The Australian Society for Operations Research (ASOR) was founded in 1972 and has about 400 members nationwide. ASOR, like other national societies, is affiliated to the International Federation of Operational Research Societies (IFORS).

ASOR serves the professional needs of OR analysts, managers, students and educators by publishing a National Bulletin and National and Chapter newsletters. The society also serves as a focal point for operations researchers to communicate with each other and to reach out to other professional societies. **www.asor.org.au**

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The Defence Science and Technology Organisation (DSTO) Operations Research (OR) Hub provides a forum for the exchange of ideas and concepts in OR research efforts within Defence. The OR Hub runs the Defence Operations Research Symposium (DORS), an annual event, devoted to the practice of military operations research and analysis. The event covers a range of topics such as new OR techniques, novel approaches to the integration of techniques, and wargaming and simulation, presented in the form of OR case studies by a range of experts in the field.

About the 20th International Congress on Modelling and Simulation (MODSIM2013)

MSSANZ, ASOR and DORS bring together a broad spectrum of scientists who apply various mathematical modelling, simulation, statistical, engineering, spatial and computer science methodologies and skills to solving practical problems coming from a wide range of endeavours. For them, the practical matter under investigation and the available data are the driving forces behind the methodology chosen for the task, or in developing techniques required to analyse new models.

For MODSIM2013, the concept of United-Sessions (U-sessions) is being trialled. Sessions can be labelled as United-Sessions if their individual presentations clearly articulate a policy or management issue and invoke an interdisciplinary approach or multiple disciplinary perspectives in addressing them; e.g. one or more of hydrology, ecology, economics, various social sciences, soil science, agricultural science, etc. In instituting U-sessions, the aim is to promote further the 'grand challenge' problem focus and it is hoped that the innovation of such sessions will help participants share ideas and modelling approaches across sectoral interests, and perhaps lead to new collaborations.

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2	August 1976	Monash University, Melbourne, VIC
3	September 1978	The Australian National University, Canberra, ACT
4	August 1980	The University of Queensland, Brisbane, QLD
5	May 1982	The University of New England, Armidale, NSW
6	August 1984	Adelaide University, Adelaide, SA
7	May 1987	Royal Melbourne Institute of Technology, Melbourne, VIC
8	September 1989	The Australian National University, Canberra, ACT
9	December 1991	Greenmount Resort Hotel, Gold Coast, QLD
10	December 1993	The University of Western Australia, Perth, WA
11	November 1995	The University of Newcastle, Newcastle, NSW
12	December 1997	University of Tasmania, Hobart, TAS
13	December 1999	University of Waikato, New Zealand
14	December 2001	The Australian National University, Canberra, ACT
15	July 2003	Jupiters Hotel and Casino, Townsville, QLD
16	December 2005	Melbourne University, Melbourne, VIC
17	December 2007	University of Canterbury, Christchurch, New Zealand
18	July 2009	Cairns Convention Centre, Cairns, QLD
19	December 2011	Perth Convention and Exhibition Centre, Perth, WA

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Contents

Plenary speakers

The multiple roles of modelling in water resources planning and management
Professor Graeme Dandy, The University of Adelaide, Australia 1

The power and limitations of mathematical models and Plato's Cave Parable
Professor Jerzy Filar, Flinders University, Australia 1

Integrated modelling for policy support: lessons learnt and current challenges
Associate Professor Hedwig van Delden, Research Institute for Knowledge Systems, The Netherlands 2

The science and technology of forecasting severe weather
Dr Jeff Kepert, Bureau of Meteorology, Australia 2

Embracing change – modeling for resilience thinking and ecosystem stewardship
Dr Maja Schlüter, Stockholm Resilience Centre, Sweden 3

Adapting to climate change in freshwater ecosystems: multiple modelling approaches to assess processes, dynamics and strategies
Professor Paul Whitehead, University of Oxford, United Kingdom 3

The challenges of modelling and simulation for defence and national security
Dr Alex Zelinsky, Defence Science and Technology Organisation, Australia 4

Mission impossible: achieving a comprehensive approach during operations and campaigns
Dr Russell W. Glenn, The Australian National University, Australia 4

Keynote speakers

A column generation approach for the scheduling of patrol boats to provide complete patrol coverage
Chircop, P.A., Surendonk, T.J., van den Briel, M.H.L. and Walsh, T. 5

Modelling Australian land use sharing for multiple ecosystem services at high spatial resolution
Connor, J.D., Bryan, B., Nolan, M., Stock, F., Graham, P., Ernst, A., Dunstall, S. and Hatfield-Dodds, S. 6

Modelling plankton ecosystems and the Library of Lotka
Cropp, R. 7

Regional climate projections – application ready and locally relevant
Ekström, M., Grose, M. and Whetton, P. 8

Modeling nutrient utilization in animal operations
Kebreab, E., Hansen, A.V., Theil, P.K. and Strathe, A. 9

Data integration technologies to support integrated modelling
Knapen, M.J.R., Roosenschoon, O., Lokers, R., Janssen, S., van Randen, Y. and Verweij, P. 10

Overview: spatial indicators of ecosystem patterns and processes
Ostendorf, B. 11

Framing elements for data collection in army field environments – problem structuring for acquisition of the right data right
Rees, L.L.M. and Curtis, N.J. 12

Dynamic ridesharing: opportunities for operations researchers
Savelsbergh, M. 13

Challenges and opportunities for groundwater modelling: update and highlights from the National Centre for Groundwater Research and Training
Simmons, C.T. 14

The many aspects of uncertainty in the AgMIP project
Wallach, D., Rivington, M. and Mearns, L. 15

Applied and computational mathematics

Stream Leaders: Barry Croke and Roger Braddock

A1. Industrial modelling and simulation

Session Leaders: Bob Anderssen and Julia Piantadosi

Using SIMULINK® to model and simulate supplier evaluation and selection problem
Abu-Ajamieh, A.M., Luong, L. and Marian, R. 16

A model of idea generation, spin-offs and cluster formation
Bagley, M. 17

An index of carcenogenesis using pairwise consistency
Bhavnagri, B. 18

Simulation-based operational decision support systems
Creighton, D., Johnstone, M., Le, V., Nahavandi, S. and Zhang, J. 19

A symmetry analysis of non-autonomous von Bertalanffy equations
Edwards, M.P. and Anderssen, R.S. 20

Multi-level grade control in a mining supply chain DEM
Grigoleit, M.T. and Schneider, M.S. 21

Computational modelling of particle spray coating
Hilton, J.E., Ying, D.Y. and Cleary, P.W. 22

Modelling of temporal combustion behaviour in a large-scale buoyant pool fire with detailed chemistry consideration
Hu, M., Yuen, A.C.Y., Cheung, S.C.P., Lappas, P., Chow, W.K. and Yeoh, G.H. 23

Simulation of an innovative public transport system
Kilby, P. and Robards, M. 24

Rim and tyre investigation for the in-wheel motor of an electric vehicle using simulations
Kulkarni, A. and Kapoor, A. 25

Patient flow simulation modelling – an approach conducive to multi-disciplinary collaboration towards hospital capacity management
Mackay, M., Qin, S., Clissold, A., Hakendorf, P., Ben-Tovim, D. and McDonnell, G. 26

Adaptively limiting high order discontinuous Galerkin solutions to the advection equation
Mungkasi, S. and Roberts, S.G. 27

Container packing problem for stochastic inventory and optimal ordering through integer programming
Nazari, A., Dunstall, S. and Ernst, A. 28

Impact of virtual training on safety and productivity in the mining industry
Pedram, S., Perez, P. and Dowsett, B. 29

Altering typical meteorological years data to cater for climate change
Ridley, B. and Boland, J. 30

Modelling motor vehicle emissions and population exposure in South Australia
Schultz, L., Chiera, B., Shah, P. and Boland, J. 31

On factory relocation via integer programming
Scott, C.H. and Liu, S. 32

Analysis of queuing scheduling linkage model to minimize the hiring cost of machines/equipments
Sharma, S., Gupta, D. and Sharma, S. 33

An environmental and economic performance measure for industrial supply networks
Shokravi, S. 34

Data-driven modelling and analysis of household travel mode choice
Shukla, N., Ma, J., Wickramasuriya, R. and Huynh, N. 35

Multiplicity in combustion wave behaviour for a model with competing exothermic reactions
Towers, I.N., Sidhu, H.S., Gubernov, V.V., Kolobov, A.V. and Polezhaev, A.A. 36

The aggregate association index and its links with common measurements of association in a 2x2 table: an analysis of early New Zealand gendered voting data
Tran, D., Beh, E.J., Hudson, I.L. and Moore, L.M. 37

Sport Synthesis: using simulation models to understand incentives for sporting teams to tank
Tuck, G.N. and Whitten, A.R. 38

A2. Solving practical inverse problems

Session Leaders: Bob Anderssen and Markus Hegland

Derivative spectroscopy and sparse regularization
Anderssen, R.S. and Hegland, M. 39

Sparse regularization of NIR spectra using implicit spiking and derivative spectroscopy
Anderssen, R.S., de Hoog, F.R., Wesley, I.J. and Zwart, A. 40

A first approach to resolving ambiguity in hidden terrorist group detection in communications networks
Bogomolov, T. and Chiera, B. 41

Deriving soil hydraulic properties at an intermediate scale using the cosmic-ray neutron soil moisture probe: an inverse problem
Cook, F.J. and McJannet, D.L. 42

Density estimation via optimal control
Hegland, M. and Yalçın Kaya, C. 43

Correcting for finite probe diameter in the dual probe heat pulse method of measuring soil water content
Knight, J.H. and Kluitenberg, G.J. 44

Inverse of magnetic dipole field using a reversible jump Markov chain Monte Carlo
Luo, X. and Foss, C. 45

Gravitational wave data analysis using chirplet-based matched filtering
Shettigara, C. 46

Art authentication from an inverse problems perspective
Sloggett, R.J. and Anderssen, R.S. 47

An efficient closure based method for inverse climate modelling
Zidikheri, M.J. and Frederiksen, J.S. 48

A3. Modelling of bushfire dynamics, fire weather, impact and risk

Session Leaders: Jason Sharples and Bob Cechet

High-resolution bushfire hazard mapping of the current and future climate to inform planning for the Rockhampton region
Cechet, R.P., Sanabria, L.A., French, I., Dunsmore, R. and Moore, D. 49

A methodology for evaluating the impact of visualization on decision-making under uncertainty for PHOENIX Rapidfire
Cheong, L.M., Bleisch, S., Duckham, M., Kealy, A., Tolhurst, K. and Wilkening, T. 50

Will environmental revegetation increase the threat wildfire poses to assets?
Collins, L., Penman, T.D., Price, O.F. and Bradstock, R.A. 51

Modelling the impact of climate change on lightning ignition of bushfires
Dowdy, A.J., Mills, G.A., Timbal, B. and Bates, B. 52

A comparison of the fire weather characteristics of the Melbourne dust storm (1983) and Black Saturday (2009): a high-resolution ACCESS case study
Fawcett, R.J.B., Wain, A., Thurston, W., Kepert, J.D. and Tory, K.J. 53

Modelling the fire weather of the Dunalley, Tasmania fire of January 2013: an ACCESS case study
Fawcett, R.J.B., Webb, M., Thurston, W., Kepert, J.D. and Tory, K.J. 54

Australian Bushfire Fuel Classification System
Featherston, G. 55

Economic analysis of prescribed burning for wildfire management in Western Australia
Florec, V., Pannell, D.J., Burton, M., Kelso, J. and Milne, G. 56

Future fire danger and ground moisture climatology for Tasmania using a dynamically downscaled regional climate model
Fox-Hughes, P., Harris, R., Lee, G., Grose, M. and Bindoff, N. 57

FireDST: Fire Impact and Risk Evaluation Decision Support Tool – model description
French, I., Cechet, B., Yang, T. and Sanabria, A. 58

Parameter sensitivity evaluation in bushfire spread modelling
Hilton, J.E., Huston, C., Prakash, M., Miller, C. and Sullivan, A. 59

Meteorological aspects of the Margaret River fires of November 2011
Kepert, J.D. and Fawcett, R.J.B. 60

Data assimilation – or, how to make fire modelling even more useful
Kepert, J.D. and Steinle, P.J. 61

Coupled atmosphere-fire simulations of the 2003 Canberra bushfires using WRF-Sfire
Mattner, T.W. 62

A process model for forecasting conditions conducive to blow-up fire events
McRae, R.H.D. and Sharples, J.J. 63

Assessing the exposure risk of regional populations to smoke from fires
Meyer, C.P., Cope, M. and Lee, S. 64

Smoke impacts from prescribed burning in Victoria; developing a risk climatology
Meyer, C.P., Lee, S. and Cope, M. 65

A 40-year mesoscale gridded fire weather climatology for Victoria – an overview
Mills, G., Brown, T., Harris, S., Podnar, D. and Reinbold, H. 66

Characterising forest wind profiles for utilisation in fire spread models
Moon, K., Duff, T.J. and Tolhurst, K.G. 67

Simulating bushfire risk in South Australia with Phoenix (Rapidfire) gridded fire simulations
Otterbach, A., Telfer, S. and Wouters, M. 68

Coupled numerical simulations show a fire changes the weather forecast
Peace, M., Mills, G. and Mattner, T. 69

The effect of fire channelling on fire severity in the 2009 Victorian fires, Australia
Price, O.F. and Sharples, J.J. 70

Wildland–urban interface (WUI) fire modelling using PHOENIX Rapidfire: A case study in Cavaillon, France
Pugnet, L., Chong, D.M., Duff, T.J. and Tolhurst, K.G. 71

Building Fire Impact Model
Sanabria, L.A., French, I. and Cechet, R.P. 72

Mapping of Australian fire weather potential: observational and modelling studies
Sanabria, L.A., Cechet, R.P. and Li, J. 73

A fire spread index for grassland fuels
Sharples, J.J. and McRae, R.H.D. 74

Modelling fire line merging using plane curvature flow
Sharples, J.J., Towers, I.N., Wheeler, G., Wheeler, V.-M. and McCoy, J.A. 75

Examination of wind speed thresholds for vorticity-driven lateral fire spread
Sharples, J.J., Simpson, C.C. and Evans, J.P. 76

Atmosphere-fire simulation of effects of low-level jets on pyro-convective plume dynamics
Simpson, C., Katurji, M., Kiefer, M.T., Zhong, S., Charney, J.J., Heilman, W.E. and Bian, X. 77

High-resolution WRF simulation of fire weather associated with the Mt Cook Station fire
Simpson, C., Pearce, G. and Clifford, V. 78

Modelling bushfire fuel across South Australia for use in risk assessments & fire management planning
Telfer, S., Wicks, S. and Wouters, M. 79

Large-eddy simulations of bushfire plumes in the turbulent atmospheric boundary layer
Thurston, W., Tory, K.J., Fawcett, R.J.B. and Kepert, J.D. 80

From "wildlife-urban interface" to "wildfire interface zone" using dynamic fire modelling
Tolhurst, K.G., Duff, T.J. and Chong, D.M. 81

Curvature flows and barriers in fire front modelling
Wheeler, V.-M., McCoy, J.A., Wheeler, G.E. and Sharples, J.J. 82

Using wind multipliers to determine local wind speed from modeled regional data for fire spread applications
Yang, T., French, I., Cechet, R.P. and Sanabria, L.A. 83

A4. Tsunami inundation and flood modelling

Session Leader: Stephen Roberts

Are the physics we use to model deep-ocean tsunami adequate?
Allgeyer, S. and Cummins, P. 84

Predictions on arrival times of water of the St. Francis dam break flood using ANUGA
Mungkasi, S., van Drie, R. and Roberts, S.G. 85

3D tsunami/storm surge inundation modelling using SPH: advantages and challenges
Prakash, M., Woolard, F., Grant, J. and Cleary, P.W. 86

High resolution tsunami inundation simulations
Roberts, S.G., Oishi, Y. and Li, M. 87

A5. Epidemic modelling

Session Leaders: Phil Pollett, Joshua Ross, Geoff Mercer, Ross McVinish and Aminath Shausan

On epidemic models with non-linear cross-diffusion
Berres, S. and Gonzalez-Marin, J. 88

Generalised multistability in a SIRWS model of infectious disease transmission
Dafilis, M.P., Frascoli, F. and McCaw, J.M. 89

Analysis of importance of brief encounters for epidemic spread
Dawson, P. 90

Network centrality and super-spreaders in infectious disease epidemiology
Dekker, A.H. 91

Modelling the impact of vaccine coverage on maternal measles immunity
Geard, N., Glass, K., McCaw, J. and McVernon, J. 92

Modelling the seasonality of respiratory syncytial virus in young children
Hogan, A.B., Mercer, G.N., Glass, K. and Moore, H.C. 93

Developing new pharmacokinetic-pharmacodynamic models of antimalarial activity
McCaw, J.M., Zaloumis, S. and Simpson, J.A. 94

Quantifying the relative fitness of two different influenza viruses
Petrie, S., Butler, J., Hurt, A., McVernon, J. and McCaw, J. 95

Empirically grounded network models for studying epidemics: what's relevant?
Rolls, D.A., Wang, P., Pattison, P. and Robins, G. 96

A6. Disease modelling and disease surveillance

Session Leader: Peter Dawson

Modelling the spread of livestock disease on a national scale: the case for a hybrid approach
Bradhurst, R.A., Roche, S.E., Garner, M.G., Sajeev, A.S.M. and Kwan, P. 97

Probabilistic inference of disease outbreaks from a combined particle filter and Bayesian network analysis of electronic health record databases
Dawson, P., Gailis, R. and Meehan, A. 98

Modelling symptom progression in individuals for disease surveillance
Dawson, P., Meehan, A., Aubron, C., Cheng, A., Gailis, R., Lau, W.M. and Pierce, C. 99

Empirical agent-based simulation of movement: the integration of high-frequency Flying-fox tracking data with a simulation model of population dynamics in time and space
Parry, H.R., Westcott, D., McKeown, A., Zhao, K., Somers, P., Jurdak, R. and Kusy, B. 100

Modelling hepatitis C treatment strategies using empirically grounded contact network models
Rolls, D.A., Sacks-Davis, R., Jenkinson, R., McBryde, E., Pattison, P., Robins, G. and Hellard, M. 101

Estimating influenza incidence across time, space and population age from routinely collected surveillance data
Thomas, E., Shamakhy, A., McCaw, J., Grant, K., Kelly, H. and McVernon, J. 102

A7. Combining mechanistic and statistical modelling approaches

Session Leaders: Barbara Robson and Grace Chiu

Modelling Submarine Groundwater Discharge (SGD) in the estuary using radon and salinity measurements
Adiyanti, S., Santos, I. and Hipsey, M. 103

Surrogate groundwater models
Asher, M., Croke, B., Jakeman, A. and Peeters, L. 104

Physical statistics or statistical physics? A brief review of Bayesian Melding.
Chiu, G.S. and Westveld, A.H. 105

Using Bayesian hierarchical models to measure and predict the effectiveness of environmental flows for ecological responses
de Little, S.C., Webb, J.A., Miller, K.A., Rutherfurd, I.D. and Stewardson, M.J. 106

RoseDist: Generalized tool for simulating with non-standard probability distributions
Feinberg, J. and Clark, S. 107

Practical state-space modelling with LibBi
Murray, L.M. 108

Incorporating a generalised additive model of river nutrient concentrations into a mechanistic receiving water model
Robson, B.J. and Dourdet, V. 109

Grappling with time-scales – linking land use and stream ecosystem health
Rutherford, J.C. 110

Probabilistic ecosystem model for predicting the nutrient concentrations in the Gulf of Finland
Vanhatalo, J., Tuomi, L., Inkala, A., Helle, I. and Pitkänen, H. 111

A9. Spatial modelling using statistical approaches including modern statistics, geostatistics, machine learning methods U-Session

Session Leader: Jin Li

Filling gaps in daily rainfall data: a statistical approach
Hasan, M.M. and Croke, B.F.W. 112

Are spatial modelling methods sensitive to spatial reference systems for predicting marine environmental variables?
Jiang, W. and Li, J. 113

Improved sea surface temperature/rainfall forecasts by multi-model combination approach
Khan, M.Z.K., Mehrotra, R., Sharma, A., Wang, Q.J., Schepen, A. and Robertson, D.E. 114

Predicting the spatial distribution of seabed gravel content using random forest, spatial interpolation methods and their hybrid methods
Li, J. 115

Levy stable distribution to model stochastic processes in GNSS time series
Montillet, J.P., Yu, K. and Tregoning, P. 116

Application of Kriging to groundwater level interpolation
Sharples, J., Daamen, C., Carrara, E., Wethasinghe, C. and Peterson, T. 117

A novel image based end-member extraction technique to map green, non-photosynthetic and bare soil fractions using Landsat data
Tan, P., Lymburner, L. and Mueller, N. 118

Combination of spatial forecasts
Wasko, C., Sharma, A. and Rasmussen, P. 119

Comparison of sum of two correlated gamma variables for Alouini's model and McKay distribution
Zakaria, R., Boland, J.W. and Moslim, N.H. 120

A10. Mathematical modelling designed to assess the impacts of global changes

Session Leaders: Lynne McArthur and Sergei Schreider

Analysis of trends in temperature and rainfall in selected regions of Australia over the last 100 years
Makuei, G., McArthur, L. and Kuleshov, Y. 121

Multifractal analysis of wind farm power output
McArthur, L., Mackenzie, S. and Boland, J. 122

Modelling the spread and growth of *Caulerpa taxifolia* in closed waterways in southern Australia using cellular automata
McArthur, L., Dunn, J. and Schreider, S. 123

An investigation of cool roofing on urban street canyon air quality
Naidu, M.K., Tian, Z.F., Medwell, P.R. and Birzer, C.H. 124

Detecting the infrastructural, demographic and climatic changes on macroalgal blooms using simulation modelling
O'Neill, K., Schreider, M., McArthur, L. and Schreider, S. 125

Optimisation modelling for gas supply in Eastern Australia
Plummer, J., Schreider, S. and McInnes, D. 126

Multi-model ensemble simulation of flood events using Bayesian Model averaging
Zhu, R., Zheng, H., Wang, E. and Zhao, W. 127

A11. Modelling the role of water in the mining industry

Session Leaders: Yun Chen and Damian Barrett

Characterising mineral slurry dewatering through laboratory centrifugation
Berres, S., Garcés, R. and Usher, S.P. 128

A process-based simulation model for strategic mine water management
Gao, L., Barrett, D., Chen, Y., Zhou, M., Cuddy, S., Paydar, Z. and Renzullo, L. 129

Secure mine water use with compliant discharge
Gao, L., Barrett, D., Chen, Y., Zhang, X., Cuddy, S., Zhou, M., Paydar, Z. and Renzullo, L. 130

A multi-criteria evaluation of water management for sustainable development in mining
Zhang, X., Gao, L., Barrett, D. and Chen, Y. 131

A scenario model for mine water management under extreme climate variability
Zhou, M., Barrett, D., Chen, Y., Gao, L., Cuddy, S., Paydar, Z. and Renzullo, L. 132

Biological systems

Stream Leaders: Malcolm McPhee and David Mayer

B1. Image analysis and plant phenomics

Session Leaders: Jinhai Cai and Hamid Laga

A phenotyping platform for transgenic wheat: method and initial results
Anbalagan, R., Kovalchuk, N., Parent, B., Kovalchuk, A., Okamoto, M., Whitford, R. and Haefele, S.M. 133

Generalised linear model and analysis of cereal plant biomass
Cespedes, M. and Cai, J. 134

Selection of parameters in active contours for the phenotypic analysis of plants
Chopin, J., Miklavcic, S.J. and Laga, H. 135

3D reconstruction, modelling and analysis of in situ root system architecture
Kumar, P., Cai, J. and Miklavcic, S. 136

Curve-based stereo matching for 3D modeling of plants
Laga, H. and Miklavcic, S.J. 137

Applications of image processing in viticulture: a review
Whalley, J. and Shanmuganathan, S. 138

B2. Agricultural systems — U-Session

Session Leaders: Aroon Parshotam and David Mayer

Using UK-DNDC for the evaluation of legume-based rotations in European organic agriculture
Angelopoulos, N., Topp, C.F.E. and Rees, R.M. 139

Modelling the response in streamflow to increased forestry plantations
Barlow, K.M., Weeks, A. and Christy, B. 140

Simulating the impact of extreme heat and frost events on wheat production: the first steps
Barlow, K.M., Christy, B.P., O'Leary, G.J., Riffkin, P.A. and Nuttal, J.G. 141

Potential for future growth in lamb supply from sheep and beef farming systems in Hawke's Bay, New Zealand
Beautrais, J.R., Vibart, R.E., Mackay, A.D. and Vogeler, I. 142

A simple carbon offset scenario tool (COST) for assessing dairy farm abatement options
Christie, K.M., Harrison, M.T., Rawnsley, R.P. and Eckard, R.J. 143

Stochastic growth models for analyzing crustacean data
Foo, C.H. and Wang, Y-G. 144

Optimal selection of whey processing facilities and technology
García-Flores, R. and Juliano, P. 145

Climate change adaptation-mitigation tradeoffs in the southern Australian livestock industry: GHG emissions
Ghahramani, A. and Moore, A.D. 146

Does increasing ewe fecundity reduce whole-farm greenhouse gas emissions intensities?
Harrison, M.T., Cullen, B.R., Rawnsley, R.P., Eckard, R.J. and Cummins, L. 147

High-resolution continental scale modelling of Australian wheat yield; biophysical and management drivers
King, D., Bryan, B.A., Zhao, G., Luo, Z. and Wang, E. 148

An interdisciplinary framework of limits and barriers to agricultural climate change adaptation
Kragt, M.E., Mugera, A. and Kolikow, S. 149

Modelling trimmed fat from commercial primal cuts
Laurenson, Y.C.S.M., Walmsley, B.J., Oddy, V.H., Greenwood, P.L. and McPhee, M.J. 150

Temperature increase and cotton crop phenology
Luo, Q., Bange, M. and Clancy, L. 151

Use of human urine as a fertilizer for corn, potato, and soybean: a case-study analysis using a reactive model
Maggi, F. and Daly, E. 152

Simulation study of low and high productivity landscapes for lamb production: comparison of two whole-farm systems
McPhee, M.J., Edwards, C. and Hegarty, R. 153

Production of a map of greenhouse gas emissions and energy use from Australian agriculture
Navarro, J., Bryan, B., Marinoni, O., Eady, S. and Halog, A. 154

A conceptual spatial system dynamics (SSD) model for structural changes in grassland farming
Neuwirth, C. and Peck, A. 155

Renewable electricity generation for energy-autonomous dairy farms, with backup technologies
Parshotam, A. and Heubeck, S. 156

Modelling water and salinity distribution in soil under advance fertigation systems in horticultural crops
Phogat, V., Skewes, M.A., Mahadevan, M. and Cox, J.W. 157

Potential for land use change to dairy in Southland, New Zealand: impact on profitability and emissions to air and water
Vibart, R.E., Vogeler, I., Dennis, S., Burggraaf, V., Beautrais, J. and Mackay, A. 158

What impact do producer measured inputs have on the prediction accuracy of BeefSpecs?
Walmsley, B.J., Mayer, D.G. and McPhee, M.J. 159

Accuracy of root modeling and its potential impact on simulation of grain yield of wheat
Zhao, Z., Wang, E., Xue, L., Wu, Y., Zhang, J. and Wang, Z. 160

B3. Biological invasion and bio-security

Session Leaders: Simon Barry and Peter Caley

To weed or not to weed? How Agent Based Models are assisting in weed management and determining optimal and economic benefits of different control strategies.
Aurambout, J-P., Weiss, J., Gajaweera, R., Steel, J., Mahr, F. and Ainsworth, N. 161

On quantifying extinction probability from the sighting record
Barry, S.C. and Caley, P. 162

Evaluating the success of pest control programs
Caley, P., Barry, S.C. and Ramsey, D. 163

When is it optimal to eradicate? A decision tool applied to Siam weed
Hester, S.M. and Cacho, O.J. 164

Do locusts seek out greener pastures? A Bayesian hierarchal analysis of the 2010–2011 Victorian Australian plague locust invasion.
Weiss, J. and McCarthy, M. 165

Computer science and engineering

Stream Leaders: Rob Argent and Tim Peterson

C2. Advances in neural networks, soft computing and machine learning and applications in natural, environmental and biological systems U-Session

Session Leader: Sandhya Samarasinghe

Gene expression based computer aided diagnosis system for breast cancer: a novel biological filter for biomarker detection
Al-yousef, A., Samarasinghe, S. and Kulasiri, D. 166

Mathematical modelling of p53 basal dynamics and DNA damage response
Chong, K.H., Samarasinghe, S. and Kulasiri, D. 167

Hydrologic model parameter optimisation
Cohen, W.J., Ollington, R.B. and Ling, F.L.N. 168

A hybrid neural network based Australian wildfire prediction: a novel approach using environmental data and satellite imagery
Das, A., Dutta, R. and Aryal, J. 169

Application of ensemble supervised machine learning to calibrate Cosmos bulk soil moisture sensor
Dutta, R., Almeida, A., Terhorst, A., Baillie, C., Worledge, D. and Smethurst, P. 170

Development of Intelligent Environmental Knowledge Discovery System (i-EKbase) for sustainable precision agriculture
Dutta, R., Morshed, A., D'Este, C., Smith, D., Shu, Y., Rahman, A. and Hellicar, A. 171

Development of a practically-significant ANN-based air pollution forecasting tool with the aid of explicit knowledge through sensitivity analysis
Elangasinghe, M.A., Singhal, N., Dirks, K.N. and Salmond, J.A. 172

Diagnostic models for mastitis detection using sensor data from automatic milking systems – current trends and future perspectives
Kharazi, M. and Samarasinghe, S. 173

Improving PMI based input selection by using different kernel bandwidths for artificial neural network models
Li, X.Y., Maier, H.R. and Zecchin, A. 174

Fuzzy representation and aggregration of Fuzzy Cognitive Maps
Obiedat, M. and Samarasinghe, S. 175

Using genetic programming for symbolic regression to detect climate change signatures
Ricketts, J.H. 176

Modeling rapid stomatal closure with Synchronous Boolean Network Approach
Waidyarathne, K.P. and Samarasinghe, S. 177

C4. Modelling and simulation in engineering

Session Leader: Amer Farhan Rafique

Comparison of computational and semi-empirical aerodynamics tools for making fit-for-purpose modelling decisions
Abeynayake, D. and Agon, A. 178

On wavelet based modeling of neural networks using graph theoretic approach
Bhosale, B. 179

A new heuristic method for generating the initial population of evolutionary algorithms for the optimisation of water distribution systems
Bi, W., Dandy, G.C. and Maier, H.R. 180

Building adaptable agent-based models – application to the electricity distribution network
Boulaire, F.A. 181

Numerical simulation of a high viscosity bubble column
Carvajal, D., Melendez-Vejar, V., Irrázabal, M. and Carlesi-Jara, C. 182

Modelling unglazed solar collectors for domestic water heating in Valparaíso (Chile)
Carvajal, D. and Araya-Muñoz, A. 183

Multi-scale modeling of materials: a basis for computational design
Cole, I.S., Chu, C., Breedon, M. and Winkler, D. 184

Planning with Lanier ultra-short stable slatwings of 1920s-1970s budget Vacu/Para-planes
Howden, P.ff. 185

A new proposed approach for star grain design and optimisation
Kamran, A., Rafique, A.F., Guozhu, L. and Zeeshan, Q. 186

Impact of calibration data variability on rainfall-runoff modeling performance in data-limited basins
Li, C.Z., Liu, J., Yu, F.L., Wang, H., Zhao, N.N. and Liu, W.J. 187

Ray tracing based fast refraction method for an object seen through a cylindrical glass
Mukai, N., Makino, Y. and Chang, Y. 188

A balancing act in heterogeneous computing – Developing the AWRA-Landscape data assimilation system
Perraud, J.-M., Collins, D., Bowden, J.C., Raupach, T., Manser, P.A., Stenson, M.P. and Renzullo, L.J. 189

Reversing the design process to aid in complex engineering problems
Rafique, A.F., Zeeshan, Q. and Kamran, A. 190

A modern take on the theoretical modelling of inertial properties of a human body for biomechanical simulations
Robertson, W.S.P. 191

Modelling and analysis of the global stability of Blasius boundary-layer flow interacting with a compliant wall
Tsigklifis, K. and Lucey, A.D. 192

A high performance, agent-based simulation of old world screwworm fly lifecycle and dispersal using a Graphics Processing Unit (GPU) platform
Welch, M., Kwan, P. and Sajeev, A.S.M. 193

Optimal control of total chlorine and free ammonia levels in a chloraminated water distribution system
Wu, W., Dandy, G.C. and Maier, H.R. 194

CFD modeling of airflows and contaminant transport in an aircraft cabin
Zhang, J., Wang, Y., Tian, Z.F., Lu, T-F. and Awadalla, M. 195

C5. Geo-informatics

Session Leaders: Subana Shanmuganathan and Philip Sallis

Microsimulation of daily movement patterns in a British city
Birkin, M., Harland, K., Malleson, N. and Martin, D. 196

Bayesian model averaging for estimating non-stationary soil moisture data
Hernández, S. and Sallis, P. 197

Climate change effects on Sri Lankan paddy yield: an initial investigation using data mining algorithms
Shanmuganathan, S. 198

Pixel clustering in spatial data mining; an example study with Kumeu wine region in New Zealand
Shanmuganathan, S. and Whalley, J. 199

Climate effects on grape production and quality at Kumeu, New Zealand
Shanmuganathan, S., Whalley, J. and Perez-Kuroki, A. 200

C7. Web services for modelling and simulation

Session Leader: Ari Jolma

A method and example system for managing provenance information in a heterogeneous process environment – a provenance architecture containing the Provenance Management System (PROMS)
Car, N.J. 201

The eReefs Information Architecture
Car, N.J. 202

Integration of wireless sensor network and web services
Ghobakhlou, A., Kmoch, A. and Sallis, P. 203

Environmental modelling as a workflow supported by web services
Jolma, A. and Ventelä, A-M. 204

Integrating scientific workflows with web services for data validation and provenance reporting
Smith, T. and Car, N.J. 205

Scientific workflows in a geographic portal for web-based spatial analysis
Touraivane, Couturier, A., Wattelez, G. and Allenbach, M. 206

C8. Integration of models with decision-support systems

Session Leaders: Ralf Denzer and Robert Argent

Characterisation of different integration strategies in scientific workflows
Bridgart, R.J. and Smith, T. 207

Application of a scenario decision support solution for combined sewer systems
Denzer, R., Schlobinski, S., Hell, Th. and Gruber, G. 208

An architecture for integrated crisis management simulation
Dihé, P., Denzer, R., Polese, M., Heikkilä, A.-M., Havlik, D., Sautter, J., Hell, Th., Schlobinski, S., Zuccaro, G. and Engelbach, W. 209

Integrated land systems modelling and optimisation
Herzig, A. and Rutledge, D. 210

Agent-based modeling and simulation framework for enhanced project schedules
Lazarova-Molnar, S. 211

Comparative code verification using redundancy in a system for national scale hydrological modelling
Leighton, B., Penton, D., Stenson, M., Manser, P., Perraud, J-M., Vleeshouwer, J., Collins, D., Bridgart, R., Mirza, F. and Kim, S. 212

Development of complex scientific workflows: towards end-to-end workflows
Penton, D.J., Freebairn, A., Bridgart, R., Murray, N. and Smith, T. 213

Approaches to distributed execution of hydrologic models: methods for ensemble Monte Carlo risk modelling with and without workflows
Pickett, T., Smith, T., Bulluss, B., Penton, D., Peeters, L., Podger, G. and Cuddy, S. 214

A distributed stream-processing infrastructure for computational models
Riedel, F. and Watson, K. 215

Creating workflows that execute external code bases that are under development
Smith, T., Car, N.J. and Smith, D. 216

Describing models on the web using OGC standards
Watson, K. and van der Schaaf, H. 217

C10. Robotics, Micromotion, Automation, Machine Condition Monitoring Automation and System of Systems

Session Leaders: Amir Anvar and Tien-Fu Lu

Modelling and simulation of tactile sensing system of fingers for intelligent robotic manipulation control
Anvar, A.P., Anvar, A.M. and Lu, T-F. 218

Intelligent submersible manipulator-robot, design, modeling, simulation and motion optimization for maritime robotic research
Guo, P., Anvar, A. and Tan, K.M. 219

Advanced oceanic power harvesting systems for autonomous undersea sensors
Hickin, J., Busuttil, E. and Anvar, A. 220

Maritime UAVs' Swarm Intelligent Robot modelling and simulation using accurate SLAM method and Rao–Blackwellized particle filters
Karimian, H. and Anvar, A. 221

Drag coefficient estimation model to simulate dynamic control of Autonomous Underwater Vehicle (AUV) motion
Tan, K.M., Lu, T-F. and Anvar, A. 222

A feasibility study on the design, development and operation of an automated oceanic wave surface glider robot
Wang, Y., Anvar, A.M., Anvar, A.P. and Hu, E. 223

Intelligent Condition Monitoring System (ICMS) for Oceanic Unmanned Air Vehicle (UAV), Unmanned Surface Vehicle (USV) and Autonomous Underwater Vehicle (AUV), Robots: a feasibility study
Xu, X. and Anvar, A. 224

Small-satellite magnetorquer attitude control system modelling and simulation
Yi, X. and Anvar, A. 225

Defence and homeland security modelling

Stream Leaders: David Marlow and Denis Shine

D1. Defence applications of modelling and simulation

Session Leaders: Alex Kalloniatis and Denis Shine

A many-on-many simulation framework to support the development of technology and algorithms for coordinated munitions
Anderson, P. 226

Self-synchronisation in C2 networks
Dekker, A.H. 227

Closing the loop with the close action environment
Finlay, L. 228

Management of interdependencies in defence capability portfolio
Garanovich, I.L., de Visser, G., Nguyen, M-T., Gill, A., Ween, A., Heseltine, T., Jiang, L., Watson, J., Taylor, R., Tailby, D. and Zadeh, H.S. 229

Assessing the military impact of capability enhancement with Netlogo using the Falklands War as a case-study
Gowlett, P. 230

Individual psychological conflict within social group dynamics
Johnson, W.T. and Ivancevic, V.G. 231

Computer-based simulation of the Wayamba Unmanned Underwater Vehicle
Madden, C. and Sgarioto, D. 232

Testing various backtracking algorithms in airborne maritime surveillance modelling
Marlow, D.O. and Murphy, J.E. 233

A multi-agent system for investigating course of action planning
Marsh, L., Shekh, S., Noack, K., Gossink, D. and Allard, T. 234

Methods and models in preparing weapon-target interaction data for combat simulations
Mazonka, O. and Shine, D. 235

Discrete event simulation of hydrographic launch and recovery operations
McAteer, S.G. and Beck, J.D. 236

Suppression of dismounted soldiers: towards improving dynamic threat assessment in closed loop combat simulations
Millikan, J., Wong, M. and Grieger, D. 237

A discrete event simulation of the joint space cell
Mukerjee, J., Nguyen, V. and Gani, R. 238

Supply chain contract parameter optimisation to manage surge in demand for military operations
Rahman, M., Thiagarajan, R., Calbert, G. and Mekhtiev, M.A. 239

Integrated submarine performance simulation
Tetlow, M.R., Howard, C.Q. and Green, J.M. 240

D2. Homeland security and emergency management applications

Session Leader: Tony Dekker

Microsimulation study of the release of Pneumonic Plague and Smallpox on a synthetic civilian population
Green, A., Piper, I. and Keep, D. 241

Statistics of chemical tracer concentration in a multi-compartment structure measured with a sensor network
Karunasekera, S., Skvortsov, A., Gunatilaka, A. and Pitaliadda, D. 242

An investigation of the effectiveness of interdiction regimes against terrorist attacks in an urban transport hub
Keep, D., Piper, I. and Green, A. 243

Algebraic models for path-based measures in time-ordered social networks
Kontoleon, N., Falzon, L. and Pattison, P. 244

Using models to compare the effectiveness of alternative complex security arrangements
Nunes-Vaz, R.A., Lord, S., Bilusich, D. and Chim, L. 245

Modeling and simulation for Homeland Security
Stamber, K.L., Brown, T.J., Pless, D.J. and Berscheid, A. 246

D3. Fleet sizing, scheduling and management

Session Leaders: David Marlow and Hossein Seif Zadeh

Development of a life-cycle sustainment conceptual model for a virtual fleet environment
Diab, H., Vodicka, R. and Perry, J. 247

Using discrete-event simulation to predict the size of a fleet of naval combat helicopters
Marlow, D.O. and Novak, A. 248

Assessing ship-based helicopter fleet sizes using a discrete event simulation
McIntosh, G.C. 249

Army vehicle fleet size analysis: modeling tool and analytical approach
Richmond, M. 250

Force generation plan automation for the Royal Australian Navy
Weir, T. 251

Defence operations research

Stream Leader: Fred Bowden

E1. Defence operations research symposium

Session Leaders: Fred Bowden and David Cox

Utilising empirical data to identify risk and prioritise treatment
Bilusich, D., Lord, S. and Nunes-Vaz, R.A. 252

A framework for determining the validation of analytical campaigns in defence experimentation
Bowden, F.D.J. and Williams, P.B. 253

Organisational storytelling with cognitive work analysis: case study of air power doctrine and strategy narrative
Brady, A., Naikar, N. and Treadwell, A. 254

Submarine Force deployment modelling
Braun, P. and Glassborow, D. 255

Modelling requirements for mission success prediction
Broderick, N., Tetlow, M., Waite, M. and Harvey, D. 256

Bridging the gap: a generic framework for behaviour representation
Dexter, R.M., Pash, K. and Piotto, J. 257

Assessing the impact of emerging technologies on the Australian Army
Dexter, P. and Krysiak, K. 258

Investment prioritisation
Garanovich, I.L., Nguyen, M-T., Wheeler, S. and Zadeh, H.S. 259

Force design for adaptivity and robustness – feasible scenario spaces and multi-scale metrics
Grisogono, A-M., Bowley, D.K. and Bowden, F.D.J. 260

ASW search and the effect of speed
Kachoyan, B.J. and Spillane, M. 261

Path analysis of infantry combat during battle of Kursk
Kosowski, L.R. 262

The Simple Dependency Ranking System – A novel method for defence capability prioritisation
Lowe, D.B., Hadley, A.L. and Pitinanondha, T. 263

Differential analysis of text-data through sentiment scoring, applications in defence capability
Malcolm, W.P. and Buntine, W. 264

Estimation and analysis schemes for collections of discrete-time integer-valued arrival processes
Malcolm, W.P. and Bennier, J. 265

Land combat vehicle terrain accessibility and impacts on conduct of operations
Manning, C.J. and Erbacher, P. 266

Exploring the role of joint in future force design
Neville, T., McKay, T. and Musgrove, L. 267

Validity checking of combat models: a Falklands War dataset
Pincombe, B. and Pincombe, A.H. 268

Operations research meets science communication
Stanton, B.A. 269

Analysis support for Land 19, Phase 7: an integrated approach
Tramoundanis, D., Christie, M., Landi, S. and Walmsley, T. 270

On the analysis and aggregation of expert opinion, applications in Defence science
van der Hoek, J. and Malcolm, W.P. 271

Structured time-independent capability options analysis
Williams, P.B., Bender, A., Pincombe, B. and Dilek, C. 272

Economics and finance

Stream Leaders: Michael McAleer and Les Oxley

F1. Combining information in socio-economic modelling and forecasting

Session Leader: Felix Chan

Modelling the relationship between duration and magnitude of changes in asset prices
Chan, F. and Petchey, J. 273

Testing intra-daily seasonality using Maximum Entropy Density
Chan, F. and Singh, R. 274

Spatial diffusion of air conditioners and time-varying price tariffs in residential housing
Higgins, A.J., Ren, Z., Egan, S., Paevere, P., Anticev, J. and Grozev, G. 275

Do more signals mean higher profits?
Klados, A. 276

Extreme movements of the major currencies traded in Australia
Sia, C-S. and Chan, F. 277

F2. Financial modelling and risk management

Session Leader: Baikunth Nath

Logistic models as temporal scaffoldings to mimic growth of companies in the high technology sector
Foo, D., Dong, Z. and Abidin, S. 278

The performance of hybrid ARIMA-GARCH modeling in forecasting gold price
Yaziz, S.R., Azizan, N.A., Zakaria, R. and Ahmad, M.H. 279

F3. Financial risk management

Session Leader: Michael McAleer

Optimal risk minimization of Australian energy and mining portfolios of stocks under multiple measures of risk
Arreola, J. and Powell, R. 280

Understanding the two-way relationship between the ASX and NZX Indexes: a vector threshold autoregressive modeling approach
Chan, W.S., Li, J.S.-H. and Ng, A.C.Y. 281

Time series properties of liquidation discount
Chan, F., Gould, J., Singh, R. and Yang, J.W. 282

The impact of Chinese tourists on volatility size effects and stock market performance in Taiwan
Chang, C.-L., Hsu, H.-K. and McAleer, M. 283

Modelling asset return using multivariate asymmetric mixture models with applications to estimation of Value-at-Risk
Lee, S.X. and McLachlan, G.J. 284

Sustainable fisheries and conservation management with environmental derivatives
Little, L.R., Parslow, J., Fay, G., Grafton, R.Q., Smith, A.D.M., Punt, A.E. and Tuck, G.N. 285

F4. Economic modelling

Session Leader: Les Oxley

Modelling a human well-being indicator
Abidin, S., Zhang, C. and Foo, D. 286

Dynamic bargaining and CDM low hanging fruits with endogenous total emission abatement target
Akita, J., Imai, H. and Niizawa, H. 287

Public Good Provision: Lindahl Tax, Income Tax, Commodity Tax, and Poll Tax, a simulation
Fukiharu, T. 288

Incentive aspects of the standardization of baseline in the project based mechanisms in the international environmental cooperation
Imai, H., Akita, J. and Niizawa, H. 289

Does the definition of retirement matter in estimating the effects of retirement on cognitive functioning?
Kajitani, S., Sakata, K. and McKenzie, C.R. 290

Scale effect in blockbuster research and development: the differences between production in Japanese firms and in US/EU firms
Miyashige, T. and Fujii, A. 291

Evaluation of the 2006 revision of the medical payment system in Japan by a new estimator of the power transformation model – an analysis of the length of the hospital stay for cataract operations
Nawata, K. and Kawabuchi, K. 292

Robust estimation based on the first- and third-moment restrictions of the power transformation model
Nawata, K. 293

F5. Modelling and financial management

Session Leader: David Allen

A dynamic credit ratings model
Allen, D.E., Powell, R.J. and Singh, A.K. 294

Primary sector volatility and default risk in Indonesia
Allen, D.E., Boffey, R.R., Kramadibrata, A.R., Powell, R.J. and Singh, A.K. 295

Dependence estimation and controlled CVaR portfolio optimization of a highly kurtotic Australian mining sample of stocks
Arreola, J., Allen, D. and Powell, R. 296

Intraday volatility forecast in Australian equity market
Singh, A.K., Allen, D.E. and Powell, R.J. 297

Interest rate sensitivities of externally and internally managed Australian REITs
Yong, J. and Singh, A.K. 298

F6. Quantitative and computational finance

Session Leader: Michael McAleer

Identifying efficient exchange rate dynamics from noisy data
Chan, F. 299

Volatility spillovers for stock returns and exchange rates of tourism firms in Taiwan
Chang, C.-L., Hsu, H.-K. and McAleer, M. 300

Diagnostic checking for non-stationary ARMA models: an application to financial data
Ling, S.-Q., Zhu, K. and Chong, C.-Y. 301

The international technology diffusion effect of cross-border and cooperative patents
Chang, C.-L., McAleer, M. and Tang, J.-T. 302

F7. Technology and innovation

Session Leader: Chia-Lin Chang

Dynamic impact factors and escalating journal self citations
Chang, C.-L., Maasoumi, E. and McAleer, M. 303

Generating a synthetic population in support of agent-based modeling of transportation in Sydney
Huynh, N., Namazi-Rad, M., Perez, P., Berryman, M.J., Chen, Q. and Barthelemy, J. 304

Agent based model of service providers and consumers within a dynamic mobile communications market
Mirza, F. and Beltrán, F. 305

F8. Modelling international business finance and high-frequency data in financial markets

Session Leaders: Zhaoyong Zhang and Kin-Yip Ho

Modelling extreme winners and extreme losers in New Zealand Stock Exchange
Abidin, S. and Nguyen, T. 306

Modelling the volatility-timing of funds under CPF investment scheme
Shen, X., Tsui, A.K. and Zhang, Z.Y. 307

News sentiment and states of stock return volatility: evidence from long memory and discrete choice models
Shi, Y. and Ho, K.-Y. 308

Modelling high-frequency volatility with three-state FIGARCH models
Shi, Y. and Ho, K.-Y. 309

Modelling the term structure of Japanese bond yields with the Nelson-Siegel model
Tsui, A.K., Wu, J.X. and Zhang, Z.Y. 310

Forecasting Singapore economic growth with mixed-frequency data
Tsui, A.K., Xu, C.Y. and Zhang, Z.Y. 311

The relation between news events and stock price jump: an analysis based on neural network
Wang, W., Ho, K.-Y., Liu, W. and Wang, K. 312

F9. Experimental economics

Session Leader: Duncan James

Recoverability of parameters from learning models
James, D. and Reagle, D. 313

F10. Valuing decisions under uncertainty

Session Leaders: Tanya Tarnopolskaya and Zili Zhu

Land use decisions under uncertainty: optimal strategies to switch between agriculture and afforestation
Bao, C. and Zhu, Z. 314

Valuing flexible operating strategies in nickel production under uncertainty
Bao, C., Mortazavi-Naeini, M., Northey, S., Tarnopolskaya, T., Monch, A. and Zhu, Z. 315

On adoption of new technology under uncertainty
Gaitsgory, V. and Tarnopolskaya, T. 316

Quantifying outcomes in agricultural planning
Lee, G.M., Zhu, Z. and Kirby, M. 317

When to bite the bullet? – A study of optimal strategies for reducing global warming
Luo, X. and Shevchenko, P.V. 318

The choice of stochastic process in real option valuation: selecting multiple factor models
Ozorio, L.M., Shevchenko, P. and Bastian-Pinto, C. 319

Linkage network of biserial queues with a multistage flowshop scheduling in fuzzy environment
Sharma, S., Gupta, D. and Sharma, S. 320

Energy

Stream Leaders: Graham Nathan, John Abraham and Zhao Feng Tian

G1. Solar irradiance forecasting methods

Session Leader: Khalid Addi

Probabilistic forecasting of wind farm output
Agrawal, M., Huang, J. and Boland, J. 321

Coordinated charging of electric vehicles
Albrecht, A. and Pudney, P. 322

Multivariate forecasting of solar energy
Boland, J. 323

A solar forecasting model based on a fractional Brownian motion
Calogine, D., Lauret, P., Addi, K. and David, M. 324

Review of technologies and optimisation methods for integrating renewable energy sources and storage within the Australian National Energy Market
Cirocco, L.R., Pudney, P., Belusko, M., Bruno, F. and Boland, J. 325

Synthetically interpolated five-minute direct normal irradiance
Grantham, A.P., Pudney, P.J., Boland, J.W. and Belusko, M. 326

Sensitivity analysis for concentrating solar power technologies
Webby, B. 327

G2. Integration of renewable energy into the electricity grid

Session Leaders: John Boland and Peter Pudney

Transmission loss modelling and analysis with multiple linear regression
Appalasamy, S., Gan, H.S., Jones, O.D., Moin, N.H. and Tan, C.S. 328

Expanding renewable energy by implementing Demand-side Integration
Bouckaert, S., Assoumou, E. and Maïzi, N. 329

Modelling for the electricity distribution network
Boulaire, F.A., Utting, M. and Drogemuller, R.M. 330

Accounting for renewable energy supply intermittency in energy systems modelling
Dunstall, S., ElGindy, T., Jafari, N., Ayre, M., Ernst, A.T., Graham, P., Reedman, L., Savelsbergh, M. and Woodman, S. 331

Modelling travel and charging patterns of plug-in electric vehicles
Horn, M.E.T., Grozev, G., Paevere, P. and Higgins, A. 332

Controlling micro-CHP generators as a virtual power plant
MacRae, C.A.G., Weiskircher, R., Dunstall, S., Ernst, A.T. and Kontoleon, N. 333

Performance of wind energy conversion systems under low power density wind regimes
Namoora, H., Mathew, S., Shah, H. and Lim, C.M. 334

G5. Energy reservoir characterisations and modelling

Session Leaders: Peter Dowd and Chaoshui Xu

Calculation of effective permeability in fractured porous media using finite volume method
Gou, C., Natarajan, N., Tian, Z.F. and Xu, C. 335

Calculation of equivalent permeability of different fracture intersections in fractured porous media
Tian, Z.F., Shang, J., Xu, C. and Natarajan, N. 336

G6. Biofuel modelling

Session Leaders: Rong Situ and Haiyan Miao

Simulation of biodiesel and petrodiesel pollutant kinetics
Cai, G. and Abraham, J. 337

Modelling ethylene-hydrogen jet flames in the MILD combustion regime
Evans, M.J., Tian, Z.F. and Medwell, P.R. 338

An Artificial Neural Network (ANN) model for predicting biodiesel kinetic viscosity as a function of temperature and chemical compositions
Jahirul, M.I., Senadeera, W., Brooks, P., Brown, R.J., Situ, R., Pham, P.X. and Masri, A.R. 339

Thermodynamic modeling of ethanol fumigation in a diesel engine
Situ, R., Ireland, G., Bodisco, T. and Brown, R. 340

Development of a two-dimensional internal combustion engines model using CFD for education purpose
Tian, Z.F. and Abraham, J. 341

Environment and ecology

Stream Leaders: Andre Zerger and Brett Bryan

H1. Modelling life histories of systems undergoing climate change

Session Leader: Irene Hudson

Scoping the budding and climate impacts on Eucalypt flowering: nonlinear time series decomposition modelling
Hudson, I.L. and Keatley, M.R. 342

H2. GIS and environmental modelling

Session Leaders: Shawn Laffan and Mirela Tulbure

Mean monthly radiation surfaces for Australia at 1 arc–second resolution
Austin, J.M., Gallant, J.C. and Van Niel, T. 343

A dynamic habitat mudflat model for the Coorong, South Australia
Benger, S.N. and Sharma, S.K. 344

High resolution DEMs from unmanned aerial vehicles
Dowling, T.I. and Gallant, J.C. 345

Creating a flow-oriented modelling mesh using the stream function
Gallant, J.C. and Basso, B. 346

Assessment of spatial models using ground point data: soil matrix and radiometric approach
Hill, S.J., Hancock, G.R. and Willgoose, G.R. 347

FishTracker: a GIS toolbox for kernel density estimation of animal home ranges that accounts for transit times and hard boundaries
Laffan, S.W. and Taylor, M.D. 348

Combining satellite measurements and topographic downscaling to model net radiation and aridity in mountainous terrain
Nyman, P., Sherwin, C.B., Langhans, C. and Sheridan, G.J. 349

A comparison of the performance of digital elevation model pit filling algorithms for hydrology
Senevirathne, N. and Willgoose, G. 350

Spatiotemporal dynamics of surface water networks across a global biodiversity hotspot
Tulbure, M.G., Kininmonth, S. and Broich, M. 351

Automated, web-based environment for daily fire risk assessment in New Caledonia
Wattelez, G., Touraivane, Mangeas, M., André, J. and Couturier, A. 352

Sensitivity of the BFAST algorithm to MODIS satellite and vegetation index
Watts, L.M. and Laffan, S.W. 353

H3. Species distribution modelling

Session Leader: Jin Li

A Naive Bayes classifier for modeling distributions of the common reed in southern Finland
Altartouri, A. and Jolma, A. 354

The biogeography of New Zealand reptiles
Di Virgilio, G., Laffan, S.W., Ebach, M.C. and Chapple, D.G. 355

Modelling sea urchin feeding fronts
Parshotam, A. and Cole, R. 356

A model for the marine cyanobacteria, *Trichodesmium*
Robson, B.J., Baird, M. and Wild-Allen, K. 357

Predictive modelling of five benthic habitats in shallow and turbid estuaries along the south-west coast of Australia
Tran, M., Anderson, T., Booth, D. and Li, J. 358

H4. Sensitivity, uncertainty and analysis of error in process-based agricultural and ecosystem simulation models

Session Leaders: Val Snow and Peter Thorburn

Assessing the sensitivity of nitrogen losses from cropping systems to different farm management practices
Biggs, J.S. and Thorburn, P.J. 359

Sensitivity analysis to investigate the factors controlling the effectiveness of a nitrification inhibitor in the soil
Cichota, R., Snow, V.O. and Kelliher, F.M. 360

Bayesian hierarchical modeling of soil carbon dynamics
Clifford, D., Pagendam, D., Baldock, J., Cressie, N., Farquharson, R., Farrell, M., Macdonald, L. and Murray, L. 361

Sensitivity analysis of SWAT model in the Yarra River catchment
Das, S.K., Ng, A.W.M. and Perera, B.J.C. 362

Meta-modelling the NZ-DNDC model for nitrous oxide emissions from grazed pastures
Giltrap, D.L. and Ausseil, A.-G. 363

Uncertainty in modelled soil organic carbon changes under various cropping systems in Australian cropland
Luo, Z., Wang, E., Shao, Q. and Baldock, J.A. 364

Bayesian analysis of computer code outputs (BACCO) applied to an agent-based model
Parry, H.R., Topping, C.J., Kennedy, M.C., Boatman, N.D. and Murray, A.W.A. 365

The use of generalised linear uncertainty estimation (GLUE) to assign initialisation values to conceptual soil organic matter pools in APSIM
Sharp, J. and Fletcher, A. 366

Does soil water model complexity affect the sensitivity of drainage and leaching to variation in soil hydraulic parameters?
Snow, V.O., Cichota, R., Lilburne, L., Webb, T. and Vogeler, I. 367

The benefits of sensitivity analysis in an interdisciplinary environment, a case study: the Ecomeristem model
Soulié, J.-C., Luquet, D. and Rouan, L. 368

Integrating two process-based models for assessing dairy system management impacts on N losses
Thayalakumaran, T., Vigiak, O., Beverly, C., Roberts, A., Stott, K., Robinson, B. and Freebairn, D. 369

Estimating the impact of grazing industry on catchment nitrogen loads of the Moe River catchment
Vigiak, O., Thayalakumaran, T., Beverly, C., Roberts, A. and Stott, K. 370

Nitrogen cycling under urine patches: model comparison and sensitivity analysis
Vogeler, I., Cichota, R. and Giltrap, D. 371

The uncertainty in predicting average quantities with simulation models
Wallach, D. and Thorburn, P.J. 372

Uncertainties in soil carbon modelling caused by model initialization and parameterisation
Wang, E. and Luo, Z. 373

Modelling the response of N_2O emission factor to nitrogen application rates and inter-annual climate variability
Xing, H., Liu, D.L., Wang, E., Smith, C.J., Anwar, M.R. and Yu, Q. 374

H5. Spatial inundation modelling for environmental purposes

Session Leaders: Yun Chen, Shahbaz Khan and Catherine Ticehurst

River Red Gum response to extended drought, high flow and flooding along the River Murray, South Australia
Doody, T., Benger, S.N., Pritchard, J. and Overton, I. 375

GIS-based spatial zoning for flood inundation modelling in the Murray–Darling Basin
Huang, C., Chen, Y. and Wu, J. 376

Ribbon plots – a spatial flow analysis tool for stable multiple-channel drainage networks
Kucharska, D.J., Stewardson, M.J., Ryu, D.R., Costelloe, J.F. and Sims, N. 377

Development and evaluation of a spatially explicit habitat suitability model for River Red Gum on the Murray River using an inundation model
Merrin, L.E. and Pollino, C.A. 378

Using MODIS for mapping flood events for use in hydrological and hydrodynamic models: experiences so far
Ticehurst, C.J., Chen, Y., Karim, F., Dutta, D. and Gouweleeuw, B. 379

Assessing stream restoration works in the southern Macquarie Marshes using hydrodynamic modeling
Wen, L., Ralph, T., Hosking, T., Barma, D. and Saintilan, N. 380

H6. Integrated models for exploring the impacts of, and adaptation to, climate change for coastal systems

Session Leader: Russell Richards

An integrated source-fate-effects model for sedimentary metals in Sydney estuary and catchment (Australia)
Birch, G.F. and Richards, R. 381

Generalized additive modelling helps untangle East Australian coastal processes
Hughes, L.P., Richards, R., Tomlinson, R.B. and Lemckert, C. 382

What is the role of sediment resuspension in the bioaccumulation of heavy metals in oysters?
Lee, J.H., Richards, R.G. and Birch, G.F. 383

Integrated modelling approach for climate change adaptation: the case of Surf Life Saving Australia
Sahin, O., Richards, R. and Sano, M. 384

Systems thinking and modelling for coastal zone management and climate change adaptation
Sano, M., Richards, R., Sahin, O. and Mackey, B. 385

Hydraulic modelling of predicted sea level rises in Kakadu Flood Plains
Saunders, K., Woolard, F., Prakash, M., Bayliss, P., Dutra, L. and Ward, D. 386

A coastal model supporting urban catchment management
Strauss, D., Bordet, A. and Buhr, C. 387

H7. Modelling of physio-chemical processes in the lake and estuarine systems

Session Leaders: Freeman Cook and Luke Mosley

Modelling of physicochemical processes in Lake Wivenhoe during a flood period
Aryal, R., Grinham, A. and Beecham, S. 388

Modelling acidic solute fluxes to the water column in the Lower Lakes
Cook, F.J. and Mosley, L. 389

A 3D hydrodynamic-biogeochemical model for assessing artificial oxygenation in a riverine salt-wedge estuary
Hipsey, M.R., Bruce, L.C. and Kilminster, K. 390

Sediment-water oxygen and nutrient fluxes in a hypoxic estuary
Nørlem, M., Paraska, D. and Hipsey, M.R. 391

A systematic review of the treatment of phosphorus in biogeochemical and ecological models
Robson, B.J. 392

H8. Climate change – phenology on the ground and remote – new ways of integrating knowledge

Session Leader: Irene Hudson

Comparison of reanalysis datasets for regional climate modelling
Moalafhi, D.B., Sharma, A. and Evans, J.P. 393

H9. The resilience of ecosystems and catchments

Session Leaders: Tim Peterson and Andrew Western

Wetland vegetation – hydrology co-evolution in response to rainfall variability
Coletti, J.Z., Vogwill, R. and Hipsey, M.R. 394

Multiple steady states and regime shifts in a social-ecological system
Lade, S.J., Tavoni, A., Levin, S.A. and Schlüter, M. 395

The importance of model structural complexity when simulating aquatic food webs
Li, Y. and Hipsey, M.R. 396

The emergence and existence of multiple hydrological steady states under stochastic climate forcing
Peterson, T.J. and Western, A.W. 397

The hydrologic implications of the co-evolution of forests, fire regimes and soil profiles in SE Australian uplands
Sheridan, G.J. 398

H10. Quantifying ecosystem services for sustainability appraisal

Session Leaders: Peter Khaiter and Marina Erechtchoukova

A framework for identifying and characterizing the supply and distribution of multiple ecosystem goods and services in multifunctional landscapes
Ferrer-Costa, A. and Rutledge, D. 399

Ecosystem services in environmental sustainability: a formalized approach using UML
Khaiter, P.A. and Erechtchoukova, M.G. 400

Application of a forest dynamics simulator to inform sustainable biodiversity conservation and grazing management in Australia
Ngugi, M.R., Botkin, D.B. and Doley, D. 401

H12. The role of environmental modelling in multifunctional land use and ecosystem services assessment **U-Session**

Session Leader: Martin Volk

LUTO – Modeling outlooks for land use and ecosystem services in Australia
Bryan, B.A., Nolan, M. and Connor, J.D. 402

Hydrological modelling of paired catchments with competing land uses
Camporese, M., Dean, J.F., Dresel, P.E., Webb, J. and Daly, E. 403

Use of multi-criteria analysis shell for catchment action planning: ecosystem services and threat analysis approach
Chapman, G.A., Yang, X. and Barrett, T.W. 404

The effects of climate change on ecologically relevant flow regimes and water quality attributes: a comparative study between Upper Murrumbidgee and Goulburn Broken catchments
Dyer, F., Hasan M., El Sawah, S., Croke, B.F.W., Harrison, E. and Jakeman, A.J. 405

Distributive hydrological modeling of a monsoon dominated river system in central Vietnam
Fink, M., Fischer, C., Führer, N., Firoz, A.M.B., Viet, T.Q., Laux, P. and Flügel, W.-A. 406

Quantifying impacts of agro-industrial expansion in Mato Grosso, Brazil, on watershed hydrology using the Soil and Water Assessment Tool (SWAT) model
Guzha, A.C., Nobrega, R., Kovacs, K., Amorim, R.S.S. and Gerold, G. 407

Sensitivity of land-use pattern optimisation to variation in input data and constraints
Herzig, A., Ausseil, A.-G.E. and Dymond, J.R. 408

Multi-objective spatial optimization for integrated agricultural climate change adaptation
Holzkämper, A., Klein, T., Calanca, P. and Fuhrer, J. 409

Identifying trade-offs of increasing biogas crop production in a German watershed under climate change
Lautenbach, S., Volk, M., Strauch, M., Whittaker, G. and Seppelt, R. 410

Habitat modelling: a multi-models approach to map the potential distribution of alpine vegetation assemblages in France
Marechal, D., Mikolajczak, A., Isenmann, M., Sanz, T. and Luque, S. 411

The use of models to explore IPM strategies and design pest suppressive landscapes for sustainable agricultural practice
Parry, H.R. and Schellhorn, N.A. 412

Linking Bayesian and agent-based models to simulate complex social-ecological systems in the Sonoran Desert
Pope, A.J. and Gimblett, H.R. 413

Optimising flow management for ecological response and consumptive use
Powell, S.J., Nichols, S.J., Webb, J.A., Adams, G., de Little, S.C. and Dyack, B. 414

Simple models in planning for a multifunctional landscape under changing market and climate conditions
Summers, D.M., Bryan, B.A., Lyle, G., Wells, S., McLean, J., Siebentritt, M., Moon, T. and Meyer, W. 415

Modelling the socio-ecological system dynamics of rubber agroforests to design reward mechanisms for agro-biodiversity conservation
Villamor, G.B., Djanibekov, U., Le, Q.B. and Vlek, P.L.G. 416

Using an integrated river basin model and an optimization algorithm for quantifying ecosystem services and trade-offs in large river basins – Challenges and potential solutions
Volk, M., Lautenbach, S., Strauch, M., Witing, F. and Seppelt, R. 417

H13. Multidisciplinary modelling marine and coastal resources

Session Leaders: Jarno Vanhatalo, Sakari Kuikka, Rich Little and Olivier Thebaud

Anticipating social-ecological regime shifts in the Baltic Sea
Lade, S.J., Orach, K. and Schlüter, M. 418

Evaluating the potential implications of monitoring and assessment strategies for the management of reef fish populations on the Great Barrier Reef, Australia
Little, L.R., Campbell, A., Innes, J., Kung, J., Leigh, G., Mapstone, B.D., Norman-Lopez, A., Punt, A.E. and Thebaud, O. 419

Baltic grey seals – balancing between sustainable management and fisheries
Vanhatalo, J., Ronkainen, L. and Helle, I. 420

H14. Spatio-temporal modelling for human and ecosystem health assessment

Session Leaders: Stefan Reis, Tim Oxley and Daniel Zachary

Examination of a tropospheric ozone control methodology from the explicit representation of POCPs across varying temporal and continent spatial domains
Lam, S.H.M., Saunders, S.M., Cheng, H.R. and Guo, H. 421

Modelled dispersion of emissions from a copper smelter, Karabash, Russian Federation
Osborne, N.J., Williamson, B., Aminov, P., Udachin, V., Purvis, O.W., Bellis, D., Goossens, M., Taylor, M., Wheeler, B., Wall, F., Van Veen, E., Reis, S. and Pollard, A. 422

Weather, climate, and the environment data linkage with human health and wellbeing data sets: MED-MI
Osborne, N., Golding, B., Kessel, A., Haines, A., Depledge, D., Cichowska, A., Bloomfield, D., Hajat, S., Sarran, C., Sabel, C. and Fleming, L. 423

Application of a protectability index to assess habitat eutrophication in designated areas
Oxley, T., ApSimon, H.M. and Hall, J. 424

Bridging the gap between air pollution models and epidemiological studies
Oxley, T., de Nazelle, A., Katara, C. and ApSimon, H.M. 425

Developing a virtual observatory for personal exposure assessment
Reis, S., Zambelli, P., Vieno, M. and Steinle, S. 426

Personal exposure to $PM_{2.5}$ – results from a pilot study
Steinle, S., Sabel, C.E. and Reis, S. 427

Can a regional chemistry transport model simulate high polluted areas for human health and policy studies?
Vieno, M., Reis, S., Doherty, R. and Heal, M.R. 428

Impact of chemicals and ionizing radiation on human health: need for adapted modeling techniques
Voigt, K., Scherb, H. and Bruggemann, R. 429

Air quality forecasting in Europe using statistical persistence
Zachary, D.S., Chiera, B. and Boland, J. 430

H15. Spatial indicators for ecosystem pattern and processes

Session Leader: Bertram Ostendorf

Spatio-temporal pattern of rice production in Bangladesh: interaction of climate and management practices
Ara, I. and Ostendorf, B. 431

Crop phenology based on MODIS satellite imagery as an indicator of plant available water content
Araya, S.G., Ostendorf, B., Lyle, G. and Lewis, M. 432

Drought risk to reforestation: simulation as a recurrent event
Bryan, B.A., Nolan, M. and Mpelasoka, F. 433

Linking spatial inundation indicators and hydrological modelling to improve assessment of inundation extent
Gibbs, M.S. and Clarke, K. 434

Using spatio-temporal vegetation imagery for arid lands monitoring
Lawley, E.F., Lewis, M.M. and Ostendorf, B. 435

Characteristics of MODIS BRDF shape and its relationship with land cover classes in Australia
Li, F., Jupp, D.L.B., Lymburner, L., Tan, P., McIntyre, A., Thankappan, M., Lewis, A. and Held, A. 436

How generalisable are empirical models to estimate high resolution spatial indicators of crop performance at the regional scale?
Lyle, G., Arbon, K., Clarke, K., Kilpatrick, A., Summers, D. and Ostendorf, B. 437

Habitat suitability and susceptibility modeling for strategic control of invasive Buffel grass, South Australia
Marshall, V., Ostendorf, B., Reynolds, T., Michaela, H., Tuke J. and Lewis, M. 438

An ecological footprint analysis for Illawarra Region (SA2 Level), NSW, Australia
Namazirad, A., Perez, P., Wickramasuriya, R. and Namazi-Rad, M-R. 439

New Zealand national and regional nutrient mapping using the CLUES model
Parshotam, A., Elliott, S. and Shankar, U. 440

Using NDVI dynamics as an indicator of native vegetation management in a heterogeneous and highly fragmented landscape
Turner, D., Clarke, K., Lewis, M. and Ostendorf, B. 441

Defining ecosystem processes of the Australian Great Artesian Basin springs from multi-sensor synergies
White, D.C. and Lewis, M.M. 442

H16. Bridging the divide between science and practice of natural resource planning

Session Leader: Tom Barrett

Modelling for the people: improving the accessibility of landscape scale data sets and raster modelling capabilities in NSW
Barrett, T.W., Sinha, P. and Bye, D. 443

A new, more inclusive and interactive approach to modelling spatial priorities for investment in natural resource management in NSW
Barrett, T.W., Turner, R., Thorne, J. and Lesslie, R. 444

Using Multi-criteria Analysis Shell (MCAS-S) to rapidly assess soil erosion and flooding amelioration priorities after wildfire
Chapman, G.A., Yang, X., McInnes-Clarke, S.K., Tulau, M.J. and Barrett, T.W. 445

Preliminary modelling to determine the extent of sustainability of land management practices within land capability in NSW
Chapman, G.A., Gray, J.M. and Young, J.A. 446

A large environmental data set and multiple models for decision support in a large scale environmental restoration work – a management perspective
Ventelä, A-M., Jolma, A. and Kirkkala, T. 447

Health informatics

Stream Leader: Irene Hudson

I1. Utilisation of health care systems

Session Leader: Irene Hudson

Linking ordinal log-linear models with Correspondence Analysis: an application to estimating drug-likeness in the drug discovery process
Zafar, S., Cheema, S.A., Beh, E.J., Hudson, I.L., Hudson, S.A. and Abell, A.D. 448

I2. Biomedical modelling and simulation

Session Leaders: Ben Mullins and Andrew King

Modelling of links from a laboratory test result to real-world performance: the case of pedestrian collisions
Hutchinson, T.P., Anderson, R.W.G. and Searson, D.J. 449

The modelling of carious lesion progress
Kosztołowicz, T. and Leandowska, K.D. 450

I3. Modelling health states and health networks: psychological and mental health and more

Session Leader: Irene Hudson

On issues concerning the assessment of information contained in aggregate data using the F-statistic
Cheema, S.A., Beh, E.J. and Hudson, I.L. 451

I4. Modelling data in health sciences

Session Leaders: Sejong Bae and Karan P. Singh

Modelling weight of a newborn based on baby's characteristics for low birth weight babies
Abdollahian, M., Nuryani, S. and Anggraini, D. 452

Using surveillance epidemiology and end results data to explore breast cancer mortality trend in an underserved population of Alabama, USA
Bae, S., Jackson, B.E., Ojha, R.P., Uhm, M., Fouad, M., Partridge, E. and Singh, K.P. 453

Updated meta-analysis of comparison of mortality in enteral feeding (EN) vs. parenteral nutrition (PN) or other methods in gastrointestinal cancer patients
Bartolucci, A., Bae, S. and Singh, K.P. 454

A multilevel analysis of child chronic undernutrition in Bangladesh
Das, S. and Nesa, M.K. 455

Trends in waist to thigh ratio among adults in US
Faramawi, M.F., Gandhi, S., Caffrey, J.L., Felini, M., Bae, S. and Singh, K.P. 456

A model for assessing the association in the repeated measures of depression among the elderly
Islam, M.A., Chowdhury, R.I., Bae, S. and Singh, K.P. 457

The impact of spatial scales on discretised spatial point patterns
Kang, S.Y., McGree, J. and Mengersen, K. 458

Increased risk of childhood brain tumors among children whose parents had farm-related pesticide exposures during pregnancy
Kunkle, B., Singh, K.P. and Roy, D. 459

Modelling hospital systems: optimising patient flow, discharge timing and resource allocation
Sier, D., Boyle, J., Dods, S., Khanna, S. and Sparks, R. 460

Integrative biostatistical approach shows better performance in missing data analysis using longitudinal study of pediatric head trauma
Yoo, C., Cheeti, A., Brooten, D. and Youngblut, J. 461

Logistic regression and Bayesian approaches in modeling acceptance of male circumcision in Pune, India
Yoo, C., Saxena, A., Krupp, K., Kulkarni, V., Kulkarni, S., Klausner, J.D., Devieux, J. and Madhivanan, P. 462

Combining Structure Equation Model with Bayesian Networks for predicting with high accuracy of recommending surgery for better survival in Benign prostatic hyperplasia patients
Yoo, C. and Oh, S. 463

I5. Modelling health interventions

Session Leader: Carolyn Nickson

Modelling to improve understanding of Pertussis epidemiology in Australia
Campbell, P., McCaw, J. and McVernon, J. 464

The role of short term population movement in sustaining STI prevalence in remote Australian Indigenous communities
Hui, B.B., Gray, R.T., Wilson, D.P., Ward, J.S., Smith, A.M.A., Philp, D.J., Law, M.G., Hocking, J.S. and Regan, D.G. 465

Tiered Prediction System for Preeclampsia: an integrative application of multiple models
Leemaqz, S.Y., Dekker, G.A. and Roberts, C.T. 466

ASOR – Operations research

Stream Leader: Paul Gaertner

J1. Logistics and workforce planning

Session Leaders: Simon Dunstall and Lin Zhang

Optimal procurement with demand warning
Calbert, G. and Thiagarajan, R. 467

Heuristics for incremental network flow problems
Ernst, A.T., Elgindy, T., Savelsbergh, M. and Dunstall, S. 468

A conceptual model for assessing the impact of adopting condition-based maintenance
Gallasch, G.E., Ivanova, K., Rajesh, S. and Manning, C. 469

Hamiltonian path approach to variable-interval scheduling problems with heterogeneous resources
Ramesh, D.N., Ernst, A., Krishnamoorthy, M. and Narayanan, V. 470

Data description and categorisation techniques for demand forecasting evaluation
Sherman, G. and Brealey, N. 471

J2. Optimisation day

Session Leaders: Ash Nelson and Paul Gaertner

Treatment planning optimisation for Volumetric Modulated Arc Therapy (VMAT)
Akartunalı, K. and Mak-Hau, V. 472

A bucket indexed formulation for nonpreemptive single machine scheduling problems
Boland, N., Clement, R. and Waterer, H. 473

A new criterion space search algorithm for biobjective 0-1 integer programming
Boland, N., Charkhgard, H. and Savelsbergh, M. 474

Picking items for experimental sets: measures of similarity and methods for optimisation
Boland, N., Bunder, R. and Heathcote, A. 475

Time aggregation for network design to meet time-constrained demand
Boland, N., Ernst, A., Kalinowski, T., Rocha de Paula, M., Savelsbergh, M. and Singh, G. 476

A variable sized bucket indexed formulation for nonpreemptive single machine scheduling problems
Clement, R., Boland, N. and Waterer, H. 477

Directed Voronoi Search: a method for bound constrained global optimization
Robertson, B.L., Price, C.J., Reale, M. and Brown, J.A. 478

J3. Emerging applications in operations research

Session Leader: Paul Gaertner

On the justifiability of decision support analysis
Bender, A. 479

Investigating parallel implementations of CP-Beam-ACO
Cohen, D., Thiruvady, D.R. and Ernst, A.T. 480

A structured approach to extract strategic objective categories from textual sources
Coutts, A. 481

Toward a systematic process for science and technology foresight
Crone, D.J. and Gaertner, P. 482

Multi-supplier and single retailer contracts: profit splits under equilibrium
Gallego, G. and Talebian, M. 483

Modelling of stakeholder participation in the Centre for Food Innovation
Hay, T.K.C., Curtis, N.J., Moon, T.T. and Lewis, E. 484

Factors affecting seaport capacity: managerial implications for a simulation framework
Islam, S. and Olsen, T.L. 485

Operations Research (OR) at ports: an update
Islam, S. and Olsen, T.L. 486

Development of future space concept options using creative thinking techniques in workshops
Jakobsson, Å. 487

Mathematical programming gives hard bounds of the Dirichlet Problem for partial differential equations
Kawai, R. 488

OA and OR – time for a divorce – or at least some time apart
Kelly, J. and Creighton, D. 489

Toward new combinatorial structures using a roundabout model with security related applications
Kiss, L.N. 490

Contextual Clustering, grouping and classifying problems in a defined context
Manning, C.J. and Bowden, F.D.J. 491

Modelling the uptake of energy efficient technologies in the residential sector
Marquez, L., Higgins, A., McNamara, C., Xu, C. and Foliente, G. 492

Decentralised resource scheduling with confidentiality protection
Singh, G. and O'Keefe, C.M. 493

J4. Health, education and life sciences

Session Leaders: Erhan Kozan and Patrick Tobin

The junior school class allocation problem – a mathematical programming solution
Gill, A. 494

Evaluating absolute capacity of the emergency department
Luscombe, R., Kozan, E. and Swierkowski, P. 495

Input system for simulation system with Excel
Namekawa, M., Shiono, Y., Ueda, Y. and Satoh, A. 496

UK initiative for healthcare simulation
O'Rourke, W. and Cordeaux, C. 497

A generic ambulance scheduling and rostering methodology using flow-shop scheduling techniques
Reeves, C. and Kozan, E. 498

Short term health impact of air pollution in Europe
San José, R., Pérez, J.L. and González, R.M. 499

An analytical model for the capacity usage of emergency departments
Wong, A., Kozan, E., Sinnott, M., Eley, R. and Spencer, L. 500

J5. Applications of OR in industry

Session Leaders: Paul Corry, Kari Stuart and Philip Kilby

Nomination-based session initiation protocol service for mobile ad hoc networks
Aburumman, A., Choo, K-K. R. and Lee, I. 501

Interference-Aware Multipath routing protocols for mobile ad hoc networks
Alwadiyeh, E.S., Aburumman, A. and Choo, K-K.R. 502

A branch-and-bound algorithm for scheduling unit processing time arc shutdown jobs to maximize flow through a transshipment node over time
Boland, N. and Kaur, S. 503

Modelling the capacity of the Hunter Valley coal chain to support capacity alignment of maintenance activities
Boland, N., McGowan, B., Mendes, A. and Rigterink, F. 504

Simulation and optimisation for bulk terminals
Corry, P. 505

High-order multi-objective optimisation of complex water resources systems under climate change
Godoy, W.R. 506

An interactive decision support system for open-pit mine production
Liu, S.Q. and Kozan, E. 507

Modelling scheduled rail operations within a dynamic mine to port supply chain simulation
Marshall, J., Cook, M. and Brook, G. 508

A GIS model for simulating infrastructure investments in livestock logistics: application to the northern beef industry
McFallan, S., Higgins, A., Prestwidge, D. and Laredo, L. 509

J7. Operations research for defence applications

Session Leaders: Paul Gaertner and Fred Bowden

CAGE experimentation – translating the principles of peer-to-peer distributed simulations design into practice
Bowen, D., Galister, M., O'Neill, J. and Slade, M. 511

A combined Bayesian Belief Network analysis and systems architectural approach to analyse an amphibious C4ISR system
Cao, T., Coutts, A. and Lui, F. 512

Operational synthesis for small combat teams: exploring the scenario parameter space using agent-based models
Chau, W. and Grieger, D. 513

Balancing the validity and viability of Bayesian Belief Networks for the study of national strategic decisions
Coutts, A. 514

Data collection at army and national security exercises
Curtis, N.J., Rees, L.M.L. and Hobbs, W.S.R. 515

Bayesian evolved multi-criteria system risk evaluation
Hu, Y. 516

A feasibility study on Bayesian approach for weapon system test and evaluation
Hu, Y. 517

Enabling models of partially understood red forces
Rajesh, S. and Curtis, N.J. 518

The US Army's force generation process – to simulate, or not to simulate
Stoddard, S.A. 519

A characterisation construct for capability considerations
van Antwerpen, C. 520

A campaign of experimentation employing M&S at the CFWC
Wheaton, K. and Prudat, G. 521

Cost-effective capacity testing in the Australian Army
Whitney, S.J., Hemming, D., Haebich, A. and Bowden, F.D.J. 522

Dynamic morphological exploration
Williams, P.B. and Bowden, F.D.J. 523

J8. Transport

Session Leaders: Amie Albrecht, Peter Pudney and Phil Howlett

Pickup and delivery with a solar-recharged vehicle
Albrecht, A. and Pudney, P. 524

The two train separation problem on level track
Albrecht, A., Howlett, P., Pudney, P., Vu, X. and Zhou, P. 525

Simulation model of crossing pedestrian movements for infrastructure planning
Berres, S., Huth, F., Schwandt, H. and Bärwolff, G. 526

Comparative analysis of time-dependent shortest path algorithms: an application for a multimodal trip planner
Casey, B., Guo, H. and Bhaskar, A. 527

Train scheduling and cooperative games
Kamarazaman, M., Albrecht, A. and Pudney, P. 528

Choosing efficient hubs and routes in an innovative public transport system
Kilby, P. and Robards, M. 529

An Extended Demand Responsive Connector
Lee, A. and Savelsbergh, M. 530

Optimising reclaimer schedules
Savelsbergh, M. and Kapoor, R. 531

Constructing water tank delivery schedules through combined vehicle routing and packing decisions
Stolk, J., Mann, I., Mohais, A. and Michalewicz, Z. 532

Operational modelling of livestock logistics for simulation based case studies
Zhou, M. and Higgins, A. 533

In-train forces from energy-efficient driving strategies
Zhou, P., Pudney, P. and Howlett, P. 534

J9. Environment and natural resources

Session Leaders: Andrew Millington and Jerzy Filar

Modelling and simulation of seasonal rainfall
Borwein, J., Howlett, P. and Piantadosi, J. 535

Can we trust depth-averaged models for hillslope seepage area prediction?
Bresciani, E., Davy, P. and de Dreuzy, J.-R. 536

Linear programming and the Australian Electricity Market
Filar, J.A. and Mohammadian, G. 537

Multivariate analysis-based modelling for selected environmental and resource problems in the Adelaide and Mount Lofty Ranges area
Guan, H., He, X., Ding, Z., Simmons, C.T., Hutson, J., Love, A., Zhang, X., Makhnin, O. and Wilson, J.L. 538

Simulation of regional CSG groundwater impacts – errors upscaling & multi-phase flow
Herckenrath, D., Doherty, J. and Moore, C. 539

Ocean modelling both in practice and in the classroom
Kämpf, J. 540

Evaluation of modelled and measured evaporation from a bare Vertosol soil in south east Queensland, Australia
Kodur, S., Foley, J.L., Silburn, D.M. and Waters, D. 541

The challenges and opportunities of constructing input-output frameworks in a virtual laboratory – the new NeCTAR Industrial Ecology Lab
Lenzen, M., Wiedmann, T., Geschke, A., Lane, J., Daniels, P., Kenway, S., Murray, J., Malik, A., Reynolds, C., Moran, D., Webb, D., Fry, J., Ugon, J., Poruschi, L, Baynes, T., West, J. and Boland, J. 542

The development of a Bayesian Belief Network as a decision support tool in feral camel removal operations
Lethbridge, M.R. and Harper, M.L. 543

Role of thermodynamic sorption models in radionuclide transport simulations
Payne, T.E. 544

Effects of temporal fluctuations on the width of the mixing zone in heterogeneous coastal aquifers
Pool, M., Post, V. and Simmons, C. 545

Towards decision support tools for incident managers dealing with large bushfires
van der Merwe, M. and Hearne, J.W. 546

Using scientific workflows to calibrate an Australian land surface model (AWRA-L)
Vleeshouwer, J., Perraud, J.M., Collins, D., Warren, G., Gallant, S. and Bridgart, R.J. 547

Integrated infrastructure and urban modelling

Stream Leaders: Pascal Perez and Geoff Syme

M1. Disaster management modelling and simulation

Session Leader: Andrew Sullivan

Real-time numerical simulation of storm surge inundation using high-performance computing for disaster management, Queensland
Burston, J., Nose, T. and Tomlinson, R. 548

Initial analysis of fire weather characteristics between south-east Australia and south-west of Western Australia
Lin, X.G., Sullivan, A.L., Stephenson, A.G. and Dunstall, S. 549

Information integration for emergency management: recent CSIRO case studies
Power, R., Robinson, B., Wise, C. and Cameron, M. 550

Emergency response resource quantification and prioritization
Stamber, K.L., Unis, C.J. and Gibson, J.A. 551

A national fire behaviour knowledge base for enhanced information management and better decision making
Sullivan, A., Gould, J., Cruz, M., Rucinski, C. and Prakash, M. 552

Zero cost solutions of geo-informatics acquisition, collection and production for natural disaster risk assessment
Zou, Z.C. and Lin, X.G. 553

Participatory decision making and modelling social systems

Stream Leaders: Susan Cuddy and Brian McIntosh

K2. Designing and validating agent-based models U-Session

Session Leader: Alex Smajgl

Numerical and analytical groundwater models as validators for an agent-based empirical subsurface flow modelling scheme
Bardsley, W.E. and Shokri, A. 554

How agency models inspire large scale participatory planning and its evaluation
Ferrand, N., Hassenforder, E., Ducrot, R., Barreteau, O. and Abrami, G. 555

Modeling work organization in grape production to study its environmental impacts
Martin-Clouaire, R., Rellier, J.-P., Paré, N., Voltz, M. and Biarnès, A. 556

The MASE design experience
Ralha, C.G., Abreu, C.G., Coelho, C.G.C. and Macchiavello, B. 557

Validating simulations of development outcomes in the Mekong region
Smajgl, A., Ward, J. and Egan, S. 558

Designing a simulation-supported learning process for decision makers in the Mekong region
Smajgl, A., Ward, J. and Egan, S. 559

Validating human decision making in an agent-based land-use model
Villamor, G.B., Troitzsch, K.G. and van Noordwijk, M. 560

ABM design: using empirical data to contextualise a theoretical model of cooperation in the commons
Wijermans, N. and Schlüter, M. 561

K3. Multidisciplinary decision support for natural resource management and sustainable development: policy, science, managers and stakeholders

Session Leaders: Susan Cuddy, Sakari Kuikka, Gregory Summerell and Onno Roosenschoon

Optimising economic and environmental outcomes: water quality challenges in Corner Inlet Victoria
Beverly, C., Roberts, A., Stott, K., Vigiak, O. and Doole, G. 562

Implementing and adapting the WRON-RM Use Case categories for eReefs: aiming for Interoperable Systems' requirements analysis best practice
Car, N.J. and Murray, N. 563

An integrated model to examine the effects of Sustainable Diversion Limits: a case study in the Lower Campaspe catchment
El Sawah, S., Kelly, R.A., Beverly, C., Stott, K., Patrick, M.J., Kath, J., Croke, B.F.W., Qureshi, M.E., Courtney-Barrer, B., Asher, M.J., Roberts, A. and Jakeman, A.J. 564

Integrated hydro-ecological-economic decision support framework for environmental water management
Fu, B., Akter, S., Dyack, B., Scarpa, R., Merritt, W., Dyer, F. and Grafton, Q. 565

An interactive modelling tool to support knowledge elicitation using extreme case models
Guillaume, J.H.A. and Fu, B. 566

On the importance of behavioral operational research: the case of understanding and communicating about dynamic systems
Hämäläinen, R.P., Luoma, J. and Saarinen, E. 567

Achieving greater real-world impact of research outputs: it's not rocket science
Lowell, K. 568

Supporting agricultural policy – the role of scientists and analysts in managing political risk
Matthews, K.B., Miller, D.G. and Wardell-Johnson, D. 569

The shared IA toolbox
Roosenschoon, O.R., Reis, S., Knapen, M.J.R., Jacob, K., Hüsing, T., Wascher, D.M. and van Randen, Y. 570

Customer focused science and knowledge management for sustainability in New South Wales, Australia
Summerell, G.K., Leys, J. and Wilson, K. 571

An environmental management plan in the Vavouto harbor (New Caledonia) with a statistical treatment displayed on dynamic maps
Wattelez, G., Touraivane, Allenbach, M., Mangeas, M., Couturier, A. and Bonte, C. 572

K5. Data governance

Session Leader: Mick Hartcher

Driving data management cultural change via automated provenance management systems
Car, N.J., Hartcher, M.G. and Stenson, M.P. 573

Making information models work harder
Francis, W., Atkinson, R., Box, P., Cox, S.J.D. and Yu, J. 574

A Governance Framework for Data Audit Trail creation in large multi-disciplinary projects
Hartcher, M.G. 575

Harmonising web feeds for emergency management
Power, R., Wise, C., Robinson, B. and Squire, G. 576

Data and information management for integrated research – requirements, experiences and solutions
Zander, F., Kralisch, S. and Flügel, W.-A. 577

K7. Linking climate change projections with users — U-Session

Session Leader: Steven Crimp

Net benefit assessment of illustrative climate adaptation policy for built assets
Baynes, T.M., West, J., McFallan, S., Wang, C.H., Khoo, Y.B., Herr, A., Langston, A., Beaty, M., Li, Y., Lau, K.W., Mazouz, S., Quezada, G., Wang, X., Stafford-Smith, M. and Hatfield-Dodds, S. 578

Supporting Regional Natural Resource Management (NRM) organisations to update their NRM plans for adaptation to climate change
Bohnet, I.C., Hill, R., Turton, S.M., Bell, R., Hilbert, D.W., Hinchley, D., Pressey, R.L., Rainbird, J., Standley, P.-M., Cvitanovic, C., Crowley, G., Curnock, M., Dale, A., Lyons, P., Moran, C. and Pert, P.L. 579

Experiences of user engagement and perceptions of user needs: providers of future climate information on the usefulness of the information they provide users for decision-making
Dunn, M., Howden, M. and Lindesay, J.A. 580

Informing the future of Australian mining through climate change scenarios
Hodgkinson, J.H., Loechel, B. and Crimp, S. 581

Worth a thousand words: connecting tourism operators with climate change through visualisation techniques
Lim-Camacho, L. and Ashworth, P. 582

Assessing urban water security and climate change adaptation in Makassar, Indonesia
Tjandraatmadja, G., Kirono, D.G.C., Neumann, L., Larson, S., Stone-Jovicich, S., Barkey, R.A., Amran, A. and Selintung, M. 583

K8. Integrated assessments in the context of urban systems — U-Session

Session Leaders: Magnus Moglia, Luis Neumann and Shiroma Maheepala

Increased urban heat island effect due to building height increase
Bennet, M.G. and Ewenz, C.M. 584

Marrying exploratory modelling to strategic planning: towards participatory model use
Malekpour, S., de Haan, F.J. and Brown, R.R. 585

Towards building an integrated urban water system model to inform the identification of optimal water source mixes for Adelaide
Mirza, F., Thomas, N., Maheepala, S. and Kotz, S. 586

Integrated assessment of water management strategies: framework and case study
Moglia, M., Nguyen, M.N., Neumann, L.E., Cook, S. and Nguyen, T.H. 587

Integrated assessment of future water security: the case of Makassar, Indonesia
Neumann, L., Tjandraatmadja, G., Kirono, D. and Selitung, M. 588

SEVA: A non-linear mathematical framework for climate change vulnerability assessment
Tonmoy, F.N. and El-Zein, A. 589

Water resources

Stream Leaders: Francis Chiew and David Post

L1. Flood modelling under changing climate regime

Session Leader: Ataur Rahman

Regional flood estimation in Australia: application of gene expression programming and artificial neural network techniques
Aziz, K., Rahman, A., Shamseldin, A. and Shoaib, M. 590

Techniques for assessing climate change impacts on antecedent catchment wetness and flooding
Bennett, B.S., Lambert, M., Thyer, M., Bates, B. and Westra, S. 591

Application of Monte Carlo simulation technique to design flood estimation: a case study for the Orara River catchment in New South Wales
Caballero, W.L. and Rahman, A. 592

A simple storage based floodplain inundation modelling approach in AWRA-R for estimating floodplain fluxes
Dutta, D., Lerat, J., Hughes, J., Kim, S. and Vaze, J. 593

Using spatial modelling to develop flood risk and climate adaptation capacity metrics for assessing urban community and critical infrastructure vulnerability
Espada, R. Jr., Apan, A. and McDougall, K. 594

Long term water demand forecasting: use of Monte Carlo cross validation for the best model selection
Haque, M.M., Haddad, K., Rahman, A., Hossain, M., Hagare, D. and Kibria, G. 595

Trend analysis of flood data in Australia: a case study for Victoria
Hossain, M.S., Rahman, A., Haddad, K. and Ishak, E.H. 596

LUCICAT Model as a river flow forecasting tool: an experiment with Fitzroy River catchment of Western Australia
Islam, S.A., Anwar, A.H.M.F., Ezzy, G. and Bari, M. 597

Hydrodynamic modelling of potential impacts of climate change on hydrological connectivity of floodplain wetland
Karim, F., Dutta, D., Marvanek, S., Ticehurst, C. and Petheram, C. 598

Regional flood modelling in the new Australian rainfall and runoff
Rahman, A.S., Haddad, K. and Rahman, A. 599

Challenges on modelling a large river basin with scare data: a case study of the Indus upper catchment
Sugiura, A., Fujioka, S., Nabesaka, S., Sayama, T., Iwami, Y., Fukami, K., Tanaka, S. and Takeuchi, K. 600

Estimation of water surface elevation on inundated area using satellite based information
Yorozuya, A., Kamimera, H., Okazumi, T., Iwami, Y. and Kwak, Y. 601

L2. Climate change adaptation in water resources management

Session Leaders: Biju George, Brian Davidson, Hector Malano and Krishna Kumar

Changes in flow threshold characteristics due to climate change in a semi-arid region
Aryal, S.K., Silberstein, R.P., Fu, G., Charles, S.P. and McFarlane, D.J. 602

Climate change impact studies: hydrologic model uncertainty evaluation
Athira, P., Cibin, R. and Sudheer, K.P. 603

Solar chilled drinking water sourced from thin air: modelling and simulation of a solar powered atmospheric water generator
Aye, L., George, B. and Wu, D. 604

Modelling to evaluate agricultural adaptation to climate change in southern Australia
Farquharson, R., Abadi, A., Finlayson, J., Ramilan, T., Liu, D.L., Anwar, M. and Clark, S. 605

Strategic water management for reliable mine water supply under dynamical climates
Gao, L., Connor, J.D., Barrett, D., Chen, Y. and Zhang, X. 606

An assessment of climate change impacts on streamflows in the Musi Catchment, India
Nune, R., George, B., Malano, H., Nawarathna, B., Davidson, B. and Ryu, D. 607

Adapting agriculture to reduce nutrient loads to the Baltic Sea under future climate and socio-economic conditions – a modeling study in the coastal watershed, Poland
Piniewski, M., Giełczewski, M., Kardel, I., Marcinkowski, P. and Okruszko, T. 608

Development of a framework to evaluate the hybrid water supply systems
Sapkota, M., Arora, M., Malano, H., George, B., Nawarathna, B., Sharma, A. and Moglia, M. 609

Modelling the impact of energy intensity on the economic and environmental costs of internally plumbed rainwater tanks systems
Siems, R., Sahin, O. and Stewart, R.A. 610

Assessing the performance of an ensemble approach to rainfall—runoff modelling for prediction of the impact of climate change on streamflow
Silberstein, R. and Aryal, S. 611

Rainfall—runoff model performance suggests a change in flow regime and possible lack of catchment resilience
Silberstein, R.P., Aryal, S.K., Braccia, M. and Durrant, J. 612

Spatio-temporal variation of temperature characteristics over Narmada basin – is the consistent warming trend a possible climate change signal?
Thomas, T., Sudheer, K.P., Ghosh, N.C. and Gunte, S.S. 613

Modelling estuarine wetlands under climate change and infrastructure pressure
Trivisonno, F.N., Rodríguez, J.F., Riccardi, G.A., Saco, P.M. and Stenta, H. 614

L3. Modelling and public policy

Session Leader: Kumar Savadamuthu

Exploring variability in environmental flow metrics for assessing options for farm dam low flow releases
Cetin, L.T., Alcorn, M.R., Rahman, J. and Savadamuthu, K. 615

Multi-response calibration of a rainfall runoff model to assess downstream environmental water requirements
Gibbs, M.S. and Taylor, B. 616

Groundwater models of the South Australian River Murray for the Basin Salinity Management Strategy: a policy and modelling success
Yan, W., Vears, L., Woods, J.A. and Li, C. 617

L4. Advances in modelling and control of large-scale water resources systems

Session Leaders: Stefano Galelli, Andrea Castelletti, Holger Maier, Patrick Reed, Dragon Savic, George Kuczera, Graeme Dandy and Mark Thyer

Model-based hypothesis testing for decision-making
Blakers, R.S., Croke, B.F.W., Doherty, J. and Jakeman, A.J. 618

Emulation modelling of salinity dynamics to inform real-time control of water quality in a tropical lake
Caietti-Marin, S., Galelli, S., Castelletti, A. and Goedbloed, A. 619

Numerical weather models as virtual sensors to data-driven rainfall forecasts in urban catchments
Cozzi, L., Galelli, S., Castelletti, A. and Jolivet, S. 620

Development of a SWAT model in the Yarra River catchment
Das, S.K., Ng, A.W.M. and Perera, B.J.C. 621

An irrigation model for use in river systems modelling
Hughes, J.D., Mainuddin, M., Lerat, J., Dutta, D. and Kim, S.S.H. 622

Extending rainfall-runoff models for use in environments with long–term catchment storage and forest cover changes
Hughes, J., Silberstein, R. and Grigg, A. 623

A new evaluation framework for input variable selection algorithms used in environmental modelling
Humphrey, G.B., Galelli, S., Maier, H.R., Castelletti, A., Dandy, G.C. and Gibbs, M.S. 624

An equivalent cross-section framework for reducing computational time in distributed hydrologic modelling
Khan, U., Tuteja, N.K., Ajami, H. and Sharma, A. 625

Using parallel computing for efficient large-scale hydrological modelling
Kralisch, S. 626

Reducing propagation of uncertainty in river system modelling by optimal use of streamflow data
Lerat, J., Dutta, D., Kim, S., Hughes, J. and Vaze, J. 627

Evaluating and improving simplified hydrologic models for baseflow and rainfall-runoff estimation using distributed physical models
Li, L., Maier, H.R., Lambert, M.F., Partington, D. and Simmons, C.T. 628

Assimilation of SMOS data for improving surface water management
Lievens, H., Al Bitar, A., Cabot, F., De Lannoy, G., Drusch, M., Dumedah, G., Hendricks Franssen, H.-J., Kerr, Y., Merlin, O., Pan, M., Roundy, J., Sahoo, A., Tomer, S.K., van den Berg, M.J., Vereecken, H., Verhoest, N.E.C., Walker, J.P., Wood, E.F. and Pauwels, V.R.N. 629

Mapping of flow paths in large, anastomosing arid zone rivers: Cooper Creek, Australia
Mohammadi, A., Ryu, D. and Costelloe, J.F. 630

Optimised scheduling of water supply schemes
Ng, Y.V. and Monks, I.R. 631

Optimisation of water scheduling for irrigation using ant colony algorithms
Nguyen, D.C.H., Maier, H.R., Dandy, G.C. and Ascough II, J.C. 632

Quantifying in-stream and overland flow generation mechanisms using fully integrated flow models
Partington, D.J., Maier, H.R., Brunner, P., Simmons, C.T., Werner, A.D., Therrien, R., Dandy, G.C., Frei, S. and Fleckenstein, J.H. 633

Local model emulation for Markov Chain Monte Carlo simulation of a river management model
Peeters, L., Podger, G., Smith, T., Pickett, T., Gao, L. and Cuddy, S. 634

An optimisation framework for scheduling environmental flow management alternatives in the South Australian River Murray
Szemis, J.M., Maier, H.R. and Dandy, G.C. 635

Groundwater modeling for the Mekong Delta using iMOD
Vermeulen, P., Quan, N.H., Nam, N.D.G., Hung, P.V., Tung, N.T., Thanh, T.V. and Dam, R. 636

L5. Development of an agreed set of climate projections for South Australia

Session Leaders: Simon Beecham, Wenju Cai, Steve Charles and Graham Green

Generating synthetic rainfall using a disaggregation model
Ahamed, S., Piantadosi, J., Agrawal, M. and Boland, J. 637

Atmospheric PM_{10} dispersion in the South Australian region
Aryal, R., Kamruzzaman, M. and Beecham, S. 638

The interplay between rainfall and vegetation
Boland, J. 639

Quantify trends in rainfall extremes in South Australia
Kamruzzaman, M., Beecham, S. and Metcalfe, A.V. 640

Autumn precipitation trends over southern Australia and other Southern Hemisphere midlatitude regions as simulated by CMIP5 models
Purich, A., Cowan, T., Min, S-K. and Cai, W. 641

Statistical downscaling of extreme rainfall from CMIP5 in the Onkaparinga catchment using a generalized linear model
Rashid, M.M., Beecham, S. and Chowdhury, R. 642

Suitability of a coupled hydrodynamic water quality model to predict changes in water quality from altered meteorological boundary conditions
van der Linden, L., Daly, R.I. and Burch, M.D. 643

Realism of climate modes in CMIP5 models: the implication for climate projections
Weller, E. and Cai, W. 644

Hydrological evaluation of statistical downscaling in the Onkaparinga Catchment
Westra, S., Thyer, M., Leonard, M. and Lambert, M. 645

Diagnosing hydrological non-stationarity in Scotts Creek catchment
Westra, S., Thyer, M., Leonard, M., Kavetski, D. and Lambert, M. 646

Reconciling surface and groundwater models in a climate change context
Woods, J., Jakovovic, D., Green, G., Alcoe, D., Werner, A. and Fleming, N. 647

L6. Water information and its roles in water resources assessment and management

Session Leaders: Amgad Elmahdi and Matthew Hardy

Weekly comparative evaluations of some high resolution water stress variables at the Riggs Creek OzFlux tower site
Azmi, M., Rüdiger, C. and Walker, J. 648

3D visualisation of groundwater systems
Barnett, S.R. 649

An overview of Australian Water Resources Assessment reporting
Edraki, M., Bende-Michl, U., Watson, M., Van Den Bos, R. and Biswas, F. 650

Urban CALculator Model (UrbanCALM): consistent and efficient urban water balance reporting tool for simple and complex systems
Jayatilaka, C. and Elmahdi, A. 651

WAFARi 2.0: Upgrade of an operational modelling system for the seasonal streamflow forecast service of the Bureau of Meteorology, Australia
MacDonald, A., Kent, D., Laugesen, R., Kabir, A., Schepen, A., Wilson, T., Tuteja, N. and Shin, D. 652

Rainfall-runoff modelling with downscaled rainfall forecasts for a seasonal streamflow forecast service
Shin, D., Laugesen, R., Kabir, A., Tuteja, N.K., MacDonald, A., Kent, D. and Le, B. 653

Defining a water quality vocabulary using QUDT and ChEBI
Simons, B.A., Yu, J. and Cox, S.J.D. 654

Modelled groundwater recharge and discharge: effects of climatic conditions
Wethasinghe, C., Carrara, E., Sharples, J., Srikanthan, S. and Daamen, C. 655

L7. Climate variability, trends and extremes

Session Leaders: Chris Perera, Nitin Muttil and Abdullah Yilmaz

Modelling of return periods of extreme rainfall events in Brisbane, Australia
Ahammed, F. 656

Prediction of tropical cyclone activity with coarse resolution global climate models
Charles, A., Shelton, K., Nakaegawa, T., Hendon, H. and Kuleshov, Y. 657

Assessing the impacts of changes in the Hadley Circulation on stationary Rossby wave propagation
Freitas, A.C.V., O'Kane, T.J., Frederiksen, J.S. and Ambrizzi, T. 658

Trend analysis of rainfall losses using an event-based hydrological model in eastern NSW
Loveridge, M. and Rahman, A. 659

Trends in low flows in the Mount Lofty Ranges, South Australia
Potter, N. 660

Temperature and rainfall thresholds corresponding to water consumption in Greater Melbourne, Australia
Sarker, R.C., Gato-Trinidad, S. and Imteaz, M. 661

Trends in rainfall patterns over the Tamarabarani Basin in Tamil Nadu, India
Sivapragasam, C., Balamurli, S., Deepak, M., Prakhar, A. and Muttil, N. 662

Future variations of rainfall events in the Japan region based on GCM outputs considering global warming
Suzuki, Y. and Okada, S. 663

Spatial rainfall extremes: are they changing?
Wasko, C., Sharma, A. and Westra, S. 664

Synoptic and dynamical analyses of ENSO extreme events over Australia
Whelan, J.A., Frederiksen, J.S., Frederiksen, C.S. and Osbrough, S.L. 665

L8. Statistical methods in hydrology and water quality science

Session Leaders: Monzur Imteaz and Ataur Rahman

Modelling sediment transport and deposition in shallow flow through grass buffer strips using machine learning
Akram, S., Yu, B. and Ghadiri, H. 666

Sensitivity analysis for a proposed sewer overflow screening device
Aziz, M.A., Imteaz, M.A. and Samsuzzoha, M. 667

Understanding functional efficiency of a sewer overflow screening device using combined CFD and analytical modeling
Aziz, M.A., Imteaz, M.A., Huda, N. and Naser, J. 668

Selecting reference streamflow forecasts to demonstrate the performance of NWP-forced streamflow forecasts
Bennett, J.C., Robertson, D.E., Shrestha, D.L. and Wang, Q.J. 669

Groundwater time-series modelling to quantify the impacts of land use change
Cheng, X., Peterson, T.J. and Western, A.W. 670

Effects of climate and landuse activities on water quality in the Yarra River catchment
Das, S.K., Ng, A.W.M., Perera, B.J.C. and Adhikary, S.K. 671

Assessment of the indirect calibration of a rainfall-runoff model for ungauged catchments in Flanders
de Vleeshouwer, N. and Pauwels, V.R.N. 672

Reliability analysis for rainwater harvesting system in peri-urban regions of Greater Sydney, Australia
Hajani, E., Rahman, A.S., Al-Amin, M. and Rahman, A. 673

Application of *eTank* for rainwater tank optimisation for Sydney metropolitan
Imteaz, M.A., Akbarkhiavi, S.P. and Hossain, M.A. 674

Reliability analysis of household rainwater harvesting tanks in the coastal areas of Bangladesh using daily water balance model
Karim, Md. R., Rimi, R.A. and Billah, Md. S. 675

Water quality investigation in the Hawkesbury-Nepean River in Sydney using Principal Component Analysis
Kuruppu, U., Rahman, A., Haque, M. and Sathasivan, A. 676

Challenges for including error updating in real-time hydrological error models
Li, M., Wang, Q.J. and Bennett, J.C. 677

Probabilistic flood hydrographs using Monte Carlo simulation: potential impact to flood inundation mapping
Loveridge, M., Rahman, A. and Babister, M. 678

Analysing lagged ENSO and IOD as potential predictors for long-term rainfall forecasting using multiple regression modelling
Mekanik, F. and Imteaz, M.A. 679

Capability of Artificial Neural Networks for predicting long-term seasonal rainfalls in east Australia
Mekanik, F. and Imteaz, M.A. 680

Monthly forecasts of catchment rainfall to long lead times using GCM rainfall and SSTs
Schepen, A.D. and Wang, Q.J. 681

A stochastic weather generation method for temporal precipitation simulation
Shao, Q., Wang, Q.J. and Zhang, L. 682

Regionalisation of water savings from rainwater harvesting system in Greater Sydney
Sharmeen, L., Rahman, A. and Kuruppu, U. 683

Dynamic seasonal stream flow forecasting approach – evaluation of rainfall runoff model performances
Wethasinghe, C., Tuteja, N.K. and Laugesen, R. 684

L9. Water quality and treatment

Session Leaders: John Van Leeuwen and Chris Chow

Prediction of dissolved organic matter (DOM) fractions removal using high performance size exclusion chromatography
Aslam, Z., van Leeuwen, J. and Chow, C.W.K. 685

Data driven statistical model for manganese concentration prediction in drinking water reservoirs
Bertone, E., Stewart, R.A., Zhang, H. and O'Halloran, K. 686

CatStream: an integrated catchment-stream water quality model
Hossain, I. and Imteaz, M.A. 687

Application of second-order central composite design (CCD) for optimization of river water treatment using trivalent (alum) and quadrivalent (titanium tetrachloride) coagulants
Hussain, S., van Leeuwen, J., Chow, C., Aryal, R. and Beecham, S. 688

Modelling pollutants transport and degradation through wetlands
Imteaz, M.A., Uddameri, V. and Ahsan, A. 689

An MILP model for cost-effective water treatment synthesis
Koleva, M.N., Polykarpou, E.M. and Papageorgiou, L.G. 690

Three-dimensional investigation of retention time distribution of waste stabilisation ponds
Li, M., Zhang, H., Lemckert, C., Lu, Z., Lei, L. and Stratton, H. 691

Modelling salt accumulation in an oval irrigated with recycled water
Rahman, M.M., Hagare, D., Maheshwari, B. and Dillon, P. 692

Prediction of trihalhomethanes in drinking water
van Leeuwen, J.A., Cook, D., Chow, C., Lewis, R., Korshin, G., Bridgeman, J. and Drikas, M. 693

L10. Modelling human-induced land subsidence

Session Leaders: Pietro Teatini, Shujun Yu and John Lambert

Simulation of shallow strata deformation caused by groundwater drainage in Shanghai
Jiao, X., Wu, J-C., Wang, H. and Ye, S-J. 694

Numerical modeling land subsidence arrested by artificial recharge and reduction of pumpage in Shanghai
Luo, Y., Ye, S., We, J., Wang, H., Yan, X. and Wei, Z. 695

Modeling the deformation of faulted volcano-sedimentary sequences associated to groundwater withdrawal in the Querétaro Valley, Mexico
Ochoa-González, G.H., Teatini, P., Carreón-Freyre, D. and Gambolati, G. 696

Application of the Multiscale Finite Element Method to the numerical modeling of regional land subsidence
Ye, S., Xue, Y., Wu, J., Wang, H., Wei, Z. and Yan, X. 697

The potential mechanisms of Yinguoan Earth Fissure using 3D seismic exploration data
Yu, J., Zhu, J.Q., Gong, X.L. and Yang, Y. 698

L11. Downscaling climate model data for environmental modelling

Session Leaders: Jason Evans, Jin Teng and Marie Ekstrom

Simulated impact of urban expansion on future temperature heatwaves in Sydney
Argüeso, D., Evans, J.P., Fita, L. and Bormann, K.J. 700

Initial NARCliM evaluation
Evans, J.P., Fita, L., Argüeso, D. and Liu, Y. 701

Insights from downscaling for southern Australian climate projections
Grose, M.R., Timbal, B., Katzfey, J.J., Moise, A.F., Wang, Y., Wilson, L., Ekström, M. and Whetton, P.H. 702

High resolution rainfall projections for the Greater Sydney Region
Ji, F., Riley, M., Clarke, H., Evans, J.P., Argüeso, D. and Fita, L. 703

Using large-scale diagnostic quantities to investigate change in frequency of East Coast Low events
Ji, F., Evans, J., Fita Borrell, L. and Argüeso, D. 704

Ensemble bias and variance corrected high-resolution downscaled climate projections for Southeast Asia
Katzfey, J.J., Hoffmann, P., McGregor, J.L., Nguyen, K.C. and Thatcher, M. 705

Dynamically downscaled simulations of tropical cyclones: a multi-model approach for the south-west Pacific
Lavender, S.L., Abbs, D.J. and Rafter, A. 706

Consistent Climate Scenarios: projecting representative future daily climate from global climate models based on historical climate data
Ricketts, J.H., Kokic, P.N. and Carter, J.O. 707

Regional climate change projections for the Tully sugar region
Sexton, J., Everingham, Y. and Skocaj, D. 708

Comparison of future runoff projections using different downscaling methods
Teng, J., Evans, J.P., Chiew, F.H.S., Timbal, B., Vaze, J., Wang, B., Ekström, M., Charles, S. and Fu, G. 709

Evaluation of downscaled POAMA M24 for monthly and 3-monthly streamflow forecasts
Zheng, H., Wang, Q.J., Aynul, K., Shao, Q., Shin, D. and Tuteja, N. 710

L12. Impacts of climate change on urban water infrastructure

Session Leaders: Chris Perera, Nitin Muttil and Abdullah Yilmaz

Bayesian hierarchical modelling of rainfall extremes
Lehmann, E.A., Phatak, A., Soltyk, S., Chia, J., Lau, R. and Palmer, M. 711

Modeling the effects of sewer mining on odour and corrosion in sewer systems
Marleni, N., Gray, S., Sharma, A., Burn, S. and Muttil, N. 712

Implementing future climate change scenarios using a stormwater drainage model for an urban catchment in Melbourne
Molavi, S., Tran, H.D. and Muttil, N. 713

Modelling impact of extreme rainfall on sanitary sewer system by predicting rainfall derived infiltration/inflow
Nasrin, T., Tran, H.D. and Muttil, N. 714

Changes in intensity-frequency-duration relationship of heavy rainfalls at a station in Melbourne
Yilmaz, A.G. and Perera, B.J.C. 715

L13. Compound extremes: understanding process interactions in hydrology and climate science

Session Leaders: Seth Westra, Michael Leonard, Aloke Phatak and Fiona Johnson

Dynamical seasonal prediction of climate extremes in the Pacific
Charles, A., Miles, E., Griesser, A., de Wit, R., Shelton, K., Cottrill, A., Spillman, C., Hendon, H., McIntosh, P., Nakaegawa, T., Atalifo, T., Prakash, B., Seuseu, S., Nihmei, S., Church, J., Jones, D. and Kuleshov, Y. 716

Observed hydrologic non-stationarity in south-eastern Australia and implications for modelling predictions
Chiew, F.H.S., Potter, N.J., Petheram, C., Zhang, L., Vaze, J., Post, D.A. and Teng, J. 717

Simulating the combined effects of climate and wildfire on streamflow
Feikema, P.M., Sherwin, C.B. and Lane, P.N.J. 718

The use of multi-duration relationships for deriving design rainfall estimates in Australia
Johnson, F. and Tang, J. 719

Estimating the contribution of rainfall and evapotranspiration changes on future flood risk
Johnson, F., Leonard, M. and Westra, S. 720

Seasonal sea-level predictions for the Western Pacific
Miles, E., Spillman, C., McIntosh, P., Church, J., Charles, A. and de Wit, R. 721

Drought related changes in rainfall-runoff relationships and its impact on model performance
Saft, M., Perraud, J.-M., Western, A.W., Zhang, L. and Peel, M.C. 722

Thunderstorms in burned forests: compound extremes and hydro-geomorphic hazards
Sheridan, G.J., Nyman, P., Langhans, C., Jones, O. and Lane, P.N.J. 723

Investigation of statistical methods for modelling bivariate extremes
Zheng, F., Westra, S., Sisson, S. and Leonard, M. 724

L14. Data assimilation for land surface process modelling

Session Leaders: Jeff Walker, Christoph Rüdiger and Gift Dumedah

Analysis of the linearised observation operator in a land surface data assimilation scheme for numerical weather prediction
Dharssi, I., Candy, B., Bovis, K., Steinle, P. and Macpherson, B. 725

A temporal stability analysis of the Australian SMAP mission validation site
Disseldorp, D.A., Yee, M., Monerris, A. and Walker, J.P. 726

Joint model state-parameter retrieval through the evolutionary data assimilation approach
Dumedah, G. and Walker, J.P. 727

Improving soil water representation in the Australian Water Resources Assessment landscape model through the assimilation of remotely-sensed soil moisture products
Renzullo, L.J., Collins, D., Perraud, J.-M., Henderson, B., Jin, H. and Smith, A. 728

Towards land surface model validation from using satellite retrieved soil moisture
Yee, M., Walker, J.P., Dumedah, G., Monerris, A. and Rüdiger, C. 729

L15. Innovations in water engineering: the role of data-based techniques

Session Leaders: Bellie Sivakumar and Ashish Sharma

An approach to creating data-based models by formulating and simplifying over-parameterised constrained linear models
Bardsley, W.E. 730

Can the peak discharge–total volume relationship for flow pulses be used to identify flow regime change?
Costelloe, J.F., Pilkington, C. and Rice, P. 731

Understanding the relationship between model parameters, objective functions and predictions for data-based modelling with conceptual rainfall-runoff models
Guillaume, J.H.A., Shin, M-J. and Jakeman, J.D. 732

Radar rainfall estimation using a dynamic Z-R relationship with parameterization conditional to measured reflectivity
Hasan, M.M., Sharma, A., Johnson, F., Seed, A. and Mariethoz, G. 733

The impact of time resolution on modeling performance in runoff volume and peak discharge estimation
Hidayat, S., Pezzaniti, D. and Alankarage, G.H. 734

A comparison of statistical and conceptual models for monthly streamflow forecasting in the Lower South East, South Australia
Humphrey, G.B., Gibbs, M.S., Maier, H.R. and Dandy, G.C. 735

Precomputing upscaled hydraulic conductivity for complex geological structures
Jha, S.K., Wawra, F., Mariethoz, G., Mathews, G., Maheswarajah, S., Vial, J., Okello, N., De, D. and Smith, M. 736

Novelty and challenges in characterizing non-stationary bedforms in large rivers using Direct Sampling
Jha, S.K., Mariethoz, G. and Kelly, B.F.J. 737

An approach for developing and comparing empirical methods to model unaccounted losses in river system models
Kim, S.S.H., Lerat, J., Chen, J. and Hughes, J. 738

Evaluating the effect of climate change on areal reduction factors in Sydney using regional climate model projections
Li, J., Sharma, A., Johnson, F. and Evans, J. 739

Applications of approximate Bayesian computation in hydrology
Marshall, L.A., Nott, D.J. and Brown, J. 740

Assessing the non-stationarity of biases in general circulation models
Nahar, J. and Johnson, F. 741

Hydrologic data networks, connections, and dynamics
Sivakumar, B. 742

An approach to detecting associations between variables for hydroclimatic forecasting
Vetrova, V.V. and Bardsley, W.E. 743

L16. Water planning and management: issues, challenges, and solutions

Session Leader: Bellie Sivakumar

Groundwater drought assessment for Barind Irrigation Project in Northwestern Bangladesh
Adhikary, S.K., Das, S.K., Saha, G.C. and Chaki, T. 744

Introducing a pressure index for water distribution networks' augmentation planning strategy
Akbarkhiavi, S.P. and Imteaz, M.A. 745

Cost-benefit analysis of farm water storage: surface storage versus managed aquifer storage
Arshad, M., Qureshi, M.E. and Jakeman, A.J. 746

New approaches for groundwater salinity management and allocation reductions
Barnett, S.R. and Williamson, D. 747

Cost estimates in cost-effectiveness analysis of water quality monitoring systems
Erechtchoukova, M.G. and Khaiter, P.A. 748

A water resource allocation model for an area in the Murray–Darling Basin
Groen, L., Chivers, B., Sidoti, A., Ma, J., Cheung, T., Sow, D., Alharthy, E., Li, M., Cheng, Y., Wu, H. and Ding, L. 749

Modelling groundwater dependent ecosystems in the Willunga Basin, South Australia
Hamilton, S.H., Guillaume, J.H.A. and ElSawah, S. 750

Representing flow mixing demands in a multi-nodal CDDP model of a mixed used catchment
Mahakalanda, I., Dye, S., Read, E.G. and Starkey, S.R. 751

Evaluating watershed development impacts on physical capital using household surveys and Bayesian networks
Patch, B., Merritt, W., Reddy, R. and Rout, S. 752

Forecasting daily reference evapotranspiration for Shepparton, Victoria, Australia using numerical weather prediction outputs
Perera, K., Western, A., Nawarathna, B. and George, B. 753

Advancing ecological modelling tools for application in water resource planning
Pollino, C.A., Brown, A., Merrin, L.E., Murray, J.V. and Stratford, D.S. 754

Multi-objective decision making for basin water allocation
Roozbahani, R., Schreider, S. and Abbasi, B. 755

Dams and development: a tale of the developing world
Sivakumar, B. and Chen, J. 756

Knowledge representation using Bayesian Networks and Ontologies
Stratford, D.S., Croft, K.M. and Pollino, C.A. 757

Using Bayesian networks to advise NRM agencies how to influence the adoption of water use efficiency practices by groundwater license holders
Ticehurst, J. and Curtis, A. 758

GCM uncertainty and reservoir storage estimation: a case study of the Warragamba catchment in Australia
Woldemeskel, F.M., Sharma, A., Sivakumar, B. and Mehrotra, R. 759

Assessing freshwater availability in Africa under the current and future climate with focus on drought and water scarcity
Yang, H., Faramarzi, M. and Abbaspour, K.C. 760

L17. Regionalising hydrologic response to improve predictions of large-scale water availability

Session Leaders: Jai Vaze, Andrew Frost, Barry Croke and Cuan Petheram

Surface water modelling in data sparse and varied climate regions for bioregional assessments
Aryal, S.K., Vaze, J., Welsh, W.D. and Chiew, F.H.S. 761

How adequately do gauged tributaries represent the hydrological behaviour of ungauged tributaries in modelling large regulated catchments?
Costelloe, J.F., Adams, R. and Western, A.W. 762

Potential improvements to the Australian Water Resources Assessment system landscape (AWRA-L) model
Ramchurn, A. and Frost, A.J. 763

Bayesian analysis diagnostics: diagnosing predictive and parameter uncertainty for hydrological models
Thyer, M., Evin, G., Kavetski, D., Westra, S. and Renard, B. 764

The Australian Water Resource Assessment Modelling System (AWRA)
Vaze, J., Viney, N., Stenson, M., Renzullo, L., Van Dijk, A., Dutta, D., Crosbie, R., Lerat, J., Penton, D., Vleeshouwer, J., Peeters, L., Teng, J., Kim, S., Hughes, J., Dawes, W., Zhang, Y., Leighton, B., Perraud, J-M., Joehnk, K., Yang, A., Wang, B., Frost, A., Elmahdi, A., Smith, A. and Daamen, C. 765

Comparison of land-cover change and climate variability impacts on runoff using hydrological modelling and sensitivity-based approaches
Vaze, J., Zhang, Y. and Li, H. 766

Influence of regionalisation distance on nearest-neighbour regionalisation
Viney, N.R. and Vaze, J. 767

Catchment grouping and regional calibration for predictions in ungauged basins
Wang, B., Vaze, J., Zhang, Y.Q. and Teng, J. 768

Hydrologic signatures for runoff prediction in ungauged catchments
Zhang, Y.Q., Vaze, J. and Chiew, F.H.S. 769

L18. Visualisation and modelling for sustainable urban development

Session Leaders: Tuan Ngo, Mohsen Kalantari and Hector Malano

Urban development and the water balance: coupling land-use dynamics and the hydrological system
Batelaan, O., Salvadore, E., Bronders, J. and Schmitz, O. 770

A scenario analysis approach to distributed energy system optimisation
Christopher, P.B., Aye, L., Ngo, T. and Mendis, P. 771

Does interactive visualisation increase stakeholders' understanding? A case study of Te Waihora/Lake Ellesmere, Canterbury, New Zealand.
Otinpong, B., Charters, S., McKinnon, A. and Gidlow, B. 772

Assessing the ability of infiltration-based WSUD systems to manage channel-forming flow regimes in greenfield catchment developments: a catchment scale investigation
Subhashini, W.H.C., Hewa, G.A. and Pezzaniti, D. 773

Adapting Geospatial Business Intelligence for regional infrastructure planning
Wickramasuriya, R., Perez, P., Ma, J. and Berryman, M. 774

L19. Recent advances in hydrological remote sensing and applications in model calibration and prediction

Session Leaders: Justin Costelloe, Fuqin Li, Dongryeol Ryu and Chun-Hsu Su

Analysis of root-zone soil moisture control on evapotranspiration in two agriculture fields in Australia
Akuraju, V.R., Ryu, D., George, B., Ryu, Y. and Dassanayake, K. 775

Impact of observation error structure on satellite soil moisture assimilation into a rainfall-runoff model
Alvarez-Garreton, C., Ryu, D., Western, A.W., Crow, W. and Robertson, D. 776

Modelling overbank flood recharge using satellite imagery of flood inundation
Doble, R.C., Crosbie, R.S., Peeters, L., Joehnk, K. and Ticehurst, C. 777

Examining the impact of scale variations on soil moisture downscaling using temporal persistence
Dumedah, G., Walker, J.P. and Melilli, B. 778

Standing water detection using radar
Elhassan, S., Wu, X. and Walker, J.P. 779

Retrieval of soil surface roughness from active and passive microwave observations
Gao, Y., Walker, J.P., Panciera, R., Monerris, A. and Ryu, D. 780

Use of remotely sensed and forecast soil moisture data for improving monthly streamflow forecasts
Humphrey, G.B., Gibbs, M.S., Dandy, G.C. and Maier, H.R. 781

An assessment of DInSAR potential for simulating geological subsurface structure
Moghaddam, N.F., Rüdiger, C., Samsanov, S., Walker, J.P. and Hall, M. 782

Evaluation of real-time satellite rainfall products in semi-arid/arid Australia
Pipunic, R.C., Ryu, D., Costelloe, J. and Su, C-H. 783

Calibration of land surface model using remotely sensed evapotranspiration and soil moisture predictions
Poovakka, A.K., Ryu, D., Renzullo, L.J., Pipunic, R. and George, B. 784

Error characterization of microwave satellite soil moisture data sets using Fourier analysis
Su, C-H., Ryu, D., Western, A.W., Crow, W.T. and Wagner, W. 785

Downscaling of coarse-resolution radiometer brightness temperature by high-resolution radar backscatter
Wu, X., Walker, J.P., Panciera, R., Rüdiger, C. and Das, N.N. 786

L20. Integrated urban water management

Session Leaders: Chris Perera, Anne Ng and Shobha Muthukumaran

Identifying safe drinking water source for establishing sustainable urban water supply scheme in Rangunia municipality, Bangladesh
Adhikary, S.K., Das, S.K., Chaki, T. and Rahman, M. 787

Multivariate statistical approach for modelling domestic water demand of Dhaka city in Bangladesh
Adhikary, S.K., Das, S.K., Islam, M.A. and Hossain, Q.S. 788

Assessment of the first flush phenomenon in three catchments with different land uses
Aryal, R., Chong, M.N., Furumai, H., Nakajima, F. and Beecham, S. 789

Modeling water use in schools: a comparative study of quarterly and monthly models
Barua, S., Ng, A.W.M., Muthukumaran, S., Huang, F., Roberts, P. and Perera, B.J.C. 790

A stochastic model of domestic water consumption and greywater generation in the Al Ain city
Chowdhury, R.K. 791

Development of a framework for the valuation of Eco-System Services of Green Infrastructure
Jayasooriya, V.M. and Ng, A.W.M. 792

A framework for optimizing residential water reuse at the cluster scale: performance trade-offs when choosing between water sources and scale of implementation
Newman, J.P., Maier, H.R. and Dandy, G.C. 793

Modeling the effects of urban growth scenarios on water demand and runoff patterns in Dublin, Ireland
Willuweit, L., O'Sullivan, J.J. and Shahumyan, H. 794

L21. Great Barrier Reef modelling — U-Session

Session Leader: David Waters

Using multi-criteria analysis models for the prioritisation of investment in the Great Barrier Reef
Barson, M., Randall, L. and Gale, K.R. 795

Great Barrier Reef paddock to reef monitoring & modelling program
Carroll, C., Waters, D., Ellis, R., McCosker, K., Gongora, M., Chinn, C. and Gale, K.R. 796

Great Barrier Reef Source Catchment's modelling: enhanced simulation and water quality targeting through event based assessment
Dougall, C. and Carroll, C. 797

An integrated water quality modelling framework for reporting on Great Barrier Reef catchments
Ellis, R. and Searle, R. 798

Assessing the effectiveness of water quality management of the Great Barrier Reef through marine monitoring and modelling
Martin, K.C., Chinn, C., Schaffelke, B., Mueller, J., Thompson, A., McKenzie, L., Waycott, M., Devlin, M., Collier, C., Brando, V., Brinkman, R., Brodie, J. and Yorkston, H. 799

Paddock scale modelling to assess effectiveness of agricultural management practice in improving water quality in the Great Barrier Reef Catchments
Shaw, M., Silburn, D.M., Ellis, R., Searle, R., Biggs, J., Thorburn, P. and Whish, G. 800

Assessing the relative risk of land based pollutants to the Great Barrier Reef
Waterhouse, J., Brodie, J. and Maynard, J. 801

Catchment modelling scenarios to inform GBR water quality targets
Waters, D., Carroll, C., Ellis, R., McCloskey, G., Hateley, L., Packett, R., Dougall, C. and Fentie, B. 802

L22. Great Barrier Reef modelling case study

Session Leader: David Waters

Testing two simple pesticide runoff models in Northern Australian agriculture
Anzooman, M., Silburn, D.M., Waters, D. and Craig, I. 803

Modelling river constituent budgets in the Burnett Mary region, Queensland, Australia: an example of how it could be used in prioritising management actions
Fentie, B., Ellis, R., Waters, D. and Carroll, C. 804

An evaluation of hydrological models for predicting mean-annual runoff and flood quantiles for water quality modelling
Karim, F., Wilkinson, S. and Dougall, C. 805

Hydrodynamic modelling of floodplain flow residence time in a wet tropical catchment, north eastern Australia
Karim, F., Palmer, A. and Brodie, J. 806

Improved mapping of soil erodibility (K-Factor) in the Burdekin River catchment, Queensland, to aid landscape modelling
Pringle, M.J., Payne, J.E., Zund, P.R. and Orton, T.G. 807

Estimating RUSLE C-Factor values for Great Barrier Reef Catchments using satellite derived ground cover estimates
Trevithick, R. and Scarth, P. 808

Monitoring to enhance modelling – a loads monitoring program for validation of catchment models
Turner, R.D.R., Smith, R.A., Huggins, R.L., Wallace, R.M., Warne, M.St.J. and Waters, D.K. 809

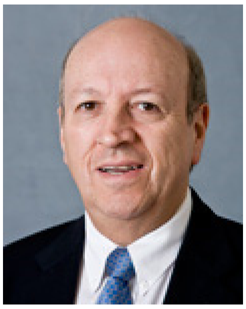
Evaluation of Simhyd, Sacramento and GR4J rainfall runoff models in two contrasting Great Barrier Reef catchments
Zhang, X., Waters, D. and Ellis, R. 810

Author index *811*

Professor Graeme Dandy

The University of Adelaide, Australia

The multiple roles of modelling in water resources planning and management



Graeme Dandy is Professor of Civil and Environmental Engineering at the University of Adelaide. He holds Bachelors and Masters Degrees in Civil Engineering from the University of Melbourne and a PhD from the Massachusetts Institute of Technology (USA). He is a Fellow of the Australian Academy of Technological Sciences and Engineering and a Fellow of the Institution of Engineers, Australia. He has published widely in the areas of water resources planning and management, optimisation of water supply and distribution systems and the use of neural networks for forecasting water resources variables.

Professor Jerzy Filar

Flinders University, Australia

The power and limitations of mathematical models and Plato's Cave Parable

Jerzy Filar is a broadly trained applied mathematician with research interests spanning a wide spectrum of both theoretical and applied topics in Operations Research, Optimisation, Game Theory, Applied Probability and Environmental Modelling. Professor Filar co-authored (with K. Vrieze) a research level text book *Competitive Markov Decision Process*, published by Springer in 1996. He also authored or co-authored approximately 100 refereed research papers. Professor Filar has an established record of research contracts/agreements with government agencies and research institutes such NSF, ARC, US EPA, World Resources Institute, DSTO and the Sir Keith and Sir Ross Smith Foundation. He is editor-in-chief of Environmental Modelling and Assessment and serves on editorial boards of Operations Research, JMAA and a number of other journals. Professor Filar is a Fellow of the Australian Mathematical Society. He has supervised 18 PhD students who are working at various universities, industries and research institutions across the world.

Associate Professor Hedwig van Delden

Research Institute for Knowledge Systems, The Netherlands

Integrated modelling for policy support: lessons learnt and current challenges

Hedwig van Delden is the director of the Research Institute for Knowledge Systems (RIKS) in Maastricht, the Netherlands and adjunct associate professor at the University of Adelaide, Australia. Her main fields of research are land use modelling, model integration, bridging the science-policy gap and scenario development. Besides her research, she manages and provides scientific leadership to national and international projects of various sizes that focus on the design, development and use of integrated models for policy support. In this capacity she has led among others the European research project LUMOCAP and the development of the DeSurvey Integrated Assessment Model. Her work has been published in several books and journals and widely presented at conferences. She is currently acting as an expert evaluator for the European Green Capital Award, organised by the European Commission.

Dr Jeff Kepert

Bureau of Meteorology, Australia

The science and technology of forecasting severe weather

Jeff Kepert works in the Centre for Australian Weather and Climate Research (CAWCR) at the Bureau of Meteorology, which undertakes research to improve scientific understanding of, and the ability to forecast, Australia's climate and weather. Jeff has also worked for the Bureau as a forecaster and as an instructor. Jeff's research interests include tropical cyclone dynamics, bushfire meteorology, air–sea exchange, boundary layers and turbulence, high-resolution wind prediction and data assimilation. He presently leads the High Impact Weather Research team within CAWCR. Jeff has degrees from the University of Western Australia (pure mathematics and statistics) and Monash University (meteorology).

Dr Maja Schlüter

Stockholm Resilience Centre, Sweden

Embracing change – modeling for resilience thinking and ecosystem stewardship

Maja Schlüter is a researcher at Stockholm Resilience Centre studying the co-evolution of social-ecological systems (SES) resulting from the interdependencies between actors, institutions and ecosystems. She is particularly interested in how the nature of their interactions affects the resilience and governance of SES. She has worked on water issues in Central Asia and fisheries in Mexico and Germany using empirical and modeling approaches. Maja has a background in ecology and applied system science and has conducted research on SES at the Helmholtz Centre for Environmental Research, Leipzig; Princeton University; and the Institute for Freshwater Ecology and Inland Fisheries, Berlin. She currently holds a starting grant of the European Research Council for modeling social-ecological systems.

Professor Paul Whitehead

University of Oxford, United Kingdom

Adapting to climate change in freshwater ecosystems: multiple modelling approaches to assess processes, dynamics and strategies

Paul has over 35 years' experience of research on water resource, water quality and pollution issues, and has a special interest in modelling, including the development of dynamic, stochastic and planning models. Model applications include simulation of catchments, rivers, lakes and reservoirs; environmental impact assessment of effluent discharges, land use and climate change, acid deposition and non-point source pollution. Paul has successfully managed 47 projects with funding by NERC, EPSRC, ESRC, EU, EA and a range of Government Departments such as DEFRA, DFID and DTI. Paul is a Professor in the Environmental Change Institute in Oxford University and is the programme director for the NERC Macronutrient Cycles. The NERC programme is a £9 million programme aimed at understanding the interacting cycles of water, nitrogen, phosphorus and carbon in river basins from the mountains or uplands to estuary and coastal systems. Paul has served on several senior Government and NERC committees such as the Thematic Programme Planning committees for the River Ecology Programme (NERC £8 million), Pollution Pathways Programme (NERC £8 million), Land Use Research Programme (NERC £12 million), Joint NERC/ AFRC Agricultural Pollution Programme (£9 million), NERC LOIS Programme (£36 million) and Environmental Diagnostics (NERC £6 million). He has published widely with over 90 papers in the refereed literature as well as being guest speaker at a wide range of conferences and meetings.

Dr Alex Zelinsky

Defence Science and Technology Organisation, Australia

The challenges of modelling and simulation for defence and national security

Dr Alex Zelinsky, D.Sc, B.Math (Hons), FIEEE, FTSE, FAICD, FIEA, is Australia's Chief Defence Scientist and Chief Executive of the Defence Science and Technology Organisation. Previously he was Group Executive for Information Sciences at CSIRO. His advisory roles include membership of the Information Technology Industry Innovation Council, the NSW Digital Economy Taskforce, the ARC Centre for Vision Science and the Defence Industry Innovation Board. Dr Zelinsky worked in robotics in Japan and later co-founded Seeing Machines, a high-technology Australian startup company that develops computer vision systems. He has won numerous engineering and science awards including the Clunies-Ross Science & Technology Award and the Eureka Prize. He is an elected fellow of several professional bodies and Vice President of the IEEE Robotics and Automation Society-Industrial Activities. Dr Zelinsky has been a professor at the Australian National University and the University of Wollongong where he completed his PhD. Named a Technology Pioneer (2003–05) by the World Economic Forum, Dr Zelinsky was Professional Engineer of the Year (Sydney Division) in 2009 and has been included in Engineers Australia's list of the 100 most influential engineers since that year.

Dr Russell W. Glenn

The Australian National University, Australia

Mission impossible: achieving a comprehensive approach during operations and campaigns

Dr Russell W. Glenn graduated from the United States Military Academy in 1975 and thereafter served as a US Army officer in the US, Republic of Korea, Germany, United Kingdom, and Southwest Asia during Operations Desert Shield and Desert Storm. His subsequent career as a security analyst includes work on urban operations and counterinsurgency, to include working with the US, Australian, Canadian, British, and Dutch militaries during development of doctrine in those fields. Dr Glenn earned his PhD in American history from the University of Kansas with secondary fields of military history and political science. Publications encompass some 50 books and reports along with over 20 articles. He is currently a member of the faculty in the Strategic and Defence Studies Centre, The Australian National University.

A column generation approach for the scheduling of patrol boats to provide complete patrol coverage

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Abstract: The problem considered in this paper is motivated by fleet sizing questions faced by the Royal Australian Navy (RAN) and Customs and Border Protection (CBP). One possible requirement of a fleet is that it should be able to provide complete coverage of a set of stipulated patrol regions located around Australia's maritime approaches. This means that there must be at least one patrol boat on station in each patrol region at any given time. This is complicated by the fact that patrol boats cannot perform patrol operations indefinitely. Before a maximum operational time has expired, a patrol boat must return to a port for a mandatory resource replenishment break, such as crew layover time, maintenance or refuelling.

In the context of meeting the stated patrol capability, a natural question which arises is the following: What is the minimum number of patrol boats required to provide a set of patrol regions with complete coverage over a planning period? This problem must be addressed by taking into consideration the operational performance of the patrol boats, the geography of the patrol network (consisting of patrol regions and ports), and the duration of a mandatory resource replenishment break. A solution to the problem will consist of a schedule for each patrol boat, containing all the information on its activities throughout the planning period, including where and when it patrols (and for how long), and at which ports it replenishes resources (and when).

Our approach to the problem is based on column generation – an advanced optimisation technique employed within linear and integer programming to solve problems in which the number of variables (columns in the constraint matrix) is too large for the direct application of standard linear programming algorithms. The technique builds upon the revised simplex algorithm of linear programming by adding candidate variables to a restricted master problem. Variables are added sequentially to the restricted master problem by solving an optimisation subproblem (called the pricing subproblem) until no more variables are found to price out favourably. In its pure form, column generation addresses continuous variable problems, and just as the standard simplex algorithm is augmented with branch-and-bound to solve integer problems, column generation is augmented with branch-and-price.

In the context of scheduling patrol boats, a decision variable represents a feasible schedule for a patrol boat over the planning period. The restricted master problem is a set covering model, for which it is relatively straightforward to construct an initial feasible solution. The decision variables are generated via pricing subproblems – this involves solving shortest path problems over a custom designed resource-space-time network, which is constructed as a directed acyclic graph. The column generation algorithm is incorporated into a branch-and-price framework, where branching occurs on the arc variables of the underlying subproblem network. The branch-and-price technique is applied over a planning period of sufficient length so as to find cyclical patrol patterns for the boats.

We outline the column generation approach to the problem of routing and scheduling patrol boats with mandatory replenishment breaks and conduct a sensitivity analysis on an example patrol network. The results show how the column generation approach may assist decision makers by highlighting the tradeoffs between patrol boat numbers, endurance, replenishment break duration and achieving complete patrol coverage with sufficient schedule slack.

Keywords: *Branch-and-price, column generation, patrol boat scheduling, resource-space-time network*

Modelling Australian land use sharing for multiple ecosystem services at high spatial resolution

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Abstract: The challenges of managing a finite land supply to influence human wellbeing through provision of: food, bio-energy, terrestrial biodiversity, water supply, global greenhouse gas balance are particularly acute for the large arid and semi-arid parts of the Australian continent faced with predicted hotter and drier climate. The Land Use Tradeoffs (LUTO) project models possible land use changes and ecosystem service outcomes for Australia with alternate global and national policy, climate, population, economic, and technological development trajectories over a time horizon to 2050. This presentation describes how LUTO involves a spatially detailed model of Australian rural land use that combines data on existing land use, production functions, input and output prices, and physical variables (including climate) to calculate the relative profitability of a wide range of potential land uses. The focus is on methodology describing: how our approach allows high resolution (1km^2 pixel scale) representation at continental scale of heterogeneous opportunity cost, while accounting for land use competition impacts on ecosystem service price supply relationships; and how we simultaneously incorporate high resolution optimisation representation of investment in biodiversity on ecological value and cost effectiveness criteria. Omission of land competition from previous parcel scale resolution modelling representing both land use change and process modelling of ecosystem service impacts has been justified because for small regions considered price impacts would be negligible. However, price impacts are significant for global scenarios involving wide spread land conversions to forest for carbon sequestration, bio-fuels production and biodiversity conservation and in a context of growing world food demand. We demonstrate an approach to overcoming the argument that such modelling is too computationally challenging which involves parallel computing, efficient data representation and piecewise linear formulation of aggregate commodity demand function representation to allow a strictly linear and continuous representation of a conceptually non-linear and discontinuous problem. The complimentary presentation in the same session by Bryan provides assessment of impacts on food and fibre production, carbon, water, energy, and biodiversity land based ecosystem services for a set of scenarios involving alternate policy options, assumptions about external drivers on land use (e.g. world agricultural productivity, food demand and carbon price) in the context of four global scenarios.

Keywords: *Land use economics, Ecosystem Services, trade-offs, carbon sequestration, bioenergy, biodiversity conservation, partial equilibrium economic modeling*

Modelling plankton ecosystems and the Library of Lotka

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Abstract: A demand for construction of computer ecosystem models of increasing complexity is emerging from the need to predict the impacts of anthropogenic activities on natural systems. In the marine field, these may include the impacts of climate change on resources such as fisheries, or on processes such as the exchange of gases between the ocean and the atmosphere. A fundamental constraint on the development of such models, and in particular their application to predict ecosystem responses to changing environments, has been the analytic intractability of complex dynamical systems. Analytic solutions to even simple nonlinear systems are rare, and geometric approaches to understanding what the solutions look like also become difficult for systems with more than three interacting populations as local stability analysis requires finding the roots of high-order polynomials. Predictions of ecosystem responses to external changes are generally obtained by calculating numerical solutions to computer models of the ecosystems. A vast number of solutions may be calculated from a model of a complex ecosystem by varying the complexity of the modelled food web, the process formulations and parameter values. A key challenge for the computer simulation approach is how to determine which of these solutions are useful.

Keywords: *Ecological model; plankton ecosystems; stability analysis; Kolmogorov systems; competition model; invasion; predator-prey model; conservative normal systems*

Regional climate projections – application ready and locally relevant

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Abstract: Global climate models (GCMs) provide projections of what future climates may look like under enhanced greenhouse gas concentrations in the atmosphere. These models and their output are central to enhancing our understanding of plausible impacts on global and regional climates. However, for many impact and adaptation studies, output from GCMs is difficult to implement simply due to its coarse resolution format (typically 100-250 km), and for some applications the data is directly unsuitable due to limitations in the GCM itself.

The practical solution to these problems is to derive regional projections from global GCM projections. The techniques to do this are many and disparate, but essentially they all fall under the heading of 'downscaling'. Because of the range in techniques, each with its particular abilities and limitations, the usual advice to users is to 'try and use as many different downscaling outputs as possible'. The reason being that in using a range of datasets, you avoid over-reliance on any particular method and exposure to its potential weaknesses.

In reality, users are rarely faced with the problem of having a large number of datasets to choose from; this is particularly true in terms of availability of datasets from the more complex downscaling methods. Given the vast range in complexity amongst downscaling methods, a perhaps more common concern of users is: how does one assess what aspects of climate change are contained in the downscaled dataset? Thus, whilst the recommendation to consider a wide range of downscaled data is valid, a more relevant recommendation should perhaps focus on how users can best assess what type of climate change information is relevant to a particular application and what downscaling approach is best suited to meet those needs.

In this presentation we attempt to provide guidance on how to select downscaling methodologies based on the needs of a particular application. To do so, we provide a summary of the most common approaches and give general guidance on their respective abilities and limitations. We then consider these approaches relative to the terms ***climate realism*** and ***change realism***, where the former concerns characteristics that makes the data 'look' like observed data and the latter concern what properties of the projected climate is contained in the dataset. Whilst most approaches do well in terms of showing high climate realism (which is necessary for the dataset to be applicable), different approaches offer different potential value in terms of its change realism (which is needed for a dataset to be treated as reliable). High climate realism is sometimes used as a reason for attributing high confidence in regional projections. This is, however, misleading since high climate realism does not equate high change realism. Rather, high levels of change realism depend on the downscaling method's capability to transfer the GCM response to its forcing to regional scales, including the extra responses generated within the downscaling itself. Note, however, that whilst downscaling can add extra regional detail, the climate change signal cannot be improved upon, as this signal is generated solely within the GCM.

This presentation builds on advice given to Natural Resources Management (NRM) representatives, as part of the CSIRO and BoM led work on providing new climate projections funded by the Australian Government's Clean Energy Future Plan.

Keywords: *Downscaling, climate change, application focus*

Modeling nutrient utilization in animal operations

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Abstract: Environmental sustainability of animal agriculture depends on improved feed conversion efficiency and reduced environmental footprint. We use the example of sows to demonstrate quantification, deeper understanding and identification of potential mitigation of environmental burden in sow operations through development of a mathematical simulation model. The model describes energy and nutrient partitioning to predict the amount and composition of manure excretion and gaseous emissions on a daily basis. The model runs through the reproductive phases of the animal, which is the time when sows are consuming and excreting large quantities of nutrients. Outputs from animal models can potentially be used as inputs in manure/soil models such as Manure-DNDC (DeNitrification DeComposition) which requires daily input values on the quality and quantity of fresh manure to estimate emissions.

A priority was established so that nutrients are used for basic metabolism of the animals first followed by milk production and body deposition. During early lactation, the animal can also utilize body tissue to meet the demands of milk production for piglets. After checking the mathematical structure of the model, global sensitivity analysis was conducted and showed that nonlinearity in the parameters was small. The model outputs considered were the total protein and fat deposition, average urinary and fecal nitrogen excretion, average methane emission, carbon excretion and manure production. The model was evaluated using independent dataset from the literature using root mean square prediction error and concordance correlation coefficients. The gestation module predicted body fat gain better than body protein gain, which was related to predictions of body fat and protein loss from the lactation model. The mean square prediction error analysis showed that predictions (model outputs) were within 8 to 18% of the observed mean.

The process-based gestation and lactation modules developed in this study has the potential to predict body composition changes during the different stages of sows' life and also nutrient excretion from sow operations. However, further refinement and evaluation is needed in some aspects of the model in order to be used for assessment of mitigation options to reduce or optimize nutrient utilization by gestating and lactating sows. These types of models can be ideal for integrating with manure/soil process based models to assess environmental mitigation options from animal systems. In addition, the model can be reverted into computing nutritional requirements for sows and hence dietary recommendations can be calculated to meet specific production expectations.

Keywords: *Nutrient utilization, sows, environmental pollution*

Data integration technologies to support integrated modelling

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Abstract: Over the recent years the scientific activities of our organisation in large research projects show a shifting priority from model integration to the integration of data itself. Our work in several large projects on integrated modelling for impact assessment studies has clearly shown the importance of data availability for integrated modelling, but of no less importance is the integration, or alignment, of the required input data itself. Moving from the fairly technical model integration in OpenMI and OpenMI related projects, and moving towards basic semantic integration in the SEAMLESS and SENSOR projects, our focus is now shifting towards researching and applying techniques such as Semantic Web technologies to improve data discoverability, its integration, and in the future on reasoning about the constructed integrated knowledge. This paper will present an overview of the on-going work in our European 7th Framework Programme (FP7) project TREES4FUTURE, focussing on automated harvesting of forestry related data sets and enriching its meta data for search ability; the FP7 LIAISE Network of Excellence on linking impact assessment instruments such as models and data to sustainability expertise; and the FP7 research project SEMAGROW on developing visions on processing and querying large RDF triple-stores of integrated agricultural data. In the end we aim at bringing the results of all these projects together to achieve a next step in integrated modelling and to present ways to use Natural Language Processing based methods to help providing meta data.

Keywords: *Integrated Modelling, Data integration, Semantic, Web of Data, Natural language Processing*

Overview: Spatial Indicators of Ecosystem Patterns and Processes

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Abstract: In this presentation I will introduce the session "Spatial Indicators of Ecosystem Patterns and Processes". The session objectives are to identify spatial indicators or surrogates for patterns and processes that are inherently difficult to assess on-ground. There is the need to find spatial indicators of ecosystem processes through ground or airborne spatial data or smart analysis/statistical and modelling approaches.

Management of water, soil and biodiversity is management of common goods. The associated dilemma has been described by Aristotle ("the most common is the least bestowed on") or in "The Tragedy of the commons" (Hardin, Science 162). It is increasingly difficult for governments to define and defend policies that conserve the commons because personal benefits attract more voters than policies that value the commons. Decisions are increasingly scrutinized and need to be based on clear, logical, defendable and repeatable evidence; hence decision tools need to be based on information that represents ecosystem patterns and processes.

But all too often, modelling is similar to a cooking a delicate meal where the recipe calls for ingredients that are either out of season, too expensive or flat out unavailable. In particular, ground based ecosystem monitoring data is oft collected at extremely small spatial footprints, is limited to a few spatially non representative locations, is collected at unrepresentative times, or a combination of the above. There is often a discrepancy between the desired data for management and the available ground-based information. This limits empirical models but also reduces realism in spatio-temporal forcing variables in mechanistic models.

So what are the possible solutions? Advances in computer technology have enabled fast processing of large amounts of data (usually spatially explicit as well as temporally dynamic) and triggered a rapid development of the field of environmental decision support systems. I will present recent approaches that increase the spatial reality in models but I will also discuss limitations due to lacking spatial information. I will illustrate the challenges of remote sensing to identify ecosystem pattern and processes that range from the temporal wealth of coarse imagery, the long time span of moderate satellite imagery to ultra-high resolution imagery over broad regions. I will also touch on recent developments of highly accurate digital elevation models and conclude with a future outlook of possibilities for spatial information in NRM decision making.

Keywords: *Natural Resources Management, Spatio-temporal, Landscape, Ecosystems*

Framing Elements for Data Collection in Army Field Environments – Problem Structuring for Acquisition of the Right Data Right

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Abstract: Good Problem Structuring Methods (PSM) practice involves the use of agreed methods within an appropriate study environment that ensures sound process is applied in a holistic manner. This is particularly valuable where the Operations Research (OR) issue relates to an Ackoff problem or mess and where there will be different viewpoints, value sets, perceptions and positions. Many Australian Army studies fall into this category. Despite the nature of such complicated issues, progress on such considerations as equipment acquisition or improved procedures must still be made. In our view, partnership between the client (the "problem" owner) and the analytical community is key to this process. Typically the study owner would engage the Operations Researchers to develop an agreed analytical campaign of which Army field data collection would be an integral part.

In this paper we investigated if development of an agreed trial data collection plan would be amenable to such a "soft" OR approach. The notion here is that if a set of "invisibles" relating to gaining an understanding of the system of study as a whole are achieved, then the actual process of formulating a field data collection plan becomes relatively straightforward and more likely to fulfil the study owners' needs. The challenge in this case is twofold – knowing what data to collect ("the right data") and how to collect it ("the data right"). In this paper we describe our experiences in developing a data acquisition model. We detail how an agreed analytical data acquisition campaign can be designed through an appreciation of a set of *framing elements*: system understanding, stakeholder needs, analyst needs and data collection opportunities.

Adherence to this protocol means the next stage of actual identification of the key discriminating features (data) and a field data collection plan already include the twin PSM goals of a credible process and delivering a usable product. Inherent to the process are agreement of a study plan and definition of the roles and responsibilities of the study sponsor and the analysts. This paper describes how the initial framing elements can be used as a basis for developing a working model of the system, identification of the critical features and shared data collection plan which focusses attention on the discriminating factors. This data collection plan becomes part of the overall analytical study and thus contributes to providing credible, auditable and transparent insights to address the overall study question. While this paper is based on experience with Army, the concept should be applicable to other military domains.

Because of the adherence to a sound plan, the study owner can have confidence that the credibility of the process will provide protection from unhelpful criticism by other parties. It is our belief that there is a significant gap in the literature, and that papers such as this one, will help develop a Code of Best Practice for trial data collection.

Keywords: *Data collection, problem structuring, Defence*

Dynamic Ridesharing: Opportunities for Operations Researchers

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Abstract: By dynamic ridesharing, we refer to a system where an automated process employed by a rideshare provider matches up drivers and riders on very short notice, from a few hours to a few minutes before departure time. A rideshare provider lets a user offer a ride as a driver or request a ride as a rider. If a match between a driver and rider is found, the rideshare provider proposes the arrangement to the participants. If driver and rider agree with the proposed arrangement, the driver picks up the rider at an agreed time and location and delivers the rider at his or her destination. The rideshare provider automatically assesses a trip fee to the rider and reimburses the driver.

Thus, dynamic ridesharing is characterized by the following features:

- A rideshare is established on short-notice.
- The drivers providing the rides are independent private entities.
- The trip-related costs are reallocated among the rideshare participants.
- The focus is on single, non-recurring trips.
- The participants agree to a rideshare in advance.
- A system matches riders and drivers and handles communication between them.

We will present and discuss dynamic ridesharing challenges, focusing primarily, but not exclusively, on the associated optimization challenges.

Keywords: *transportation, optimisation, ridesharing*

Challenges and opportunities for groundwater modelling: Update and highlights from the National Centre for Groundwater Research and Training

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Abstract: This presentation will give an overview of some of the current challenges and future opportunities which face groundwater modelling. In order to progress quantitative evaluation and prediction of groundwater systems, major fundamental developments are required to (amongst other things): improve our conceptual understanding of the inherent physics, chemistry and groundwater dynamics associated with these problems; incorporate and simulate increasingly complex and coupled groundwater processes in the numerical simulators used to understand and quantify these processes; and to provide rigorous and quantitative assessments of model simplicity and complexity and associated levels of uncertainty. These underpin robust modelling in support of policy and decision making. The presentation will also provide an update on and some highlights from the modelling work being undertaken by the NCGRT to address these issues.

Keywords: *groundwater, dynamic modelling, numerical simulation, quantitative assessment*

The many aspects of uncertainty in the AgMIP project

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Abstract: The two principal aims of the Agricultural Model Intercomparison and Improvement Project (AgMIP) are crop model improvement and intercomparison and climate change multi-model impact assessment. In both of these areas, uncertainty has a very important role. In the intercomparison work, uncertainty is a tool for quantifying and understanding the differences between models. In the impact assessment work, uncertainty is a means to appreciate the reliability of predictions. In both cases, the fact of working with ensembles of crop models gives a new and powerful tool for evaluating uncertainty that was not available before. The purpose of this paper is to give examples of the specific uncertainty questions that arise in AgMIP, and to show how results for model ensembles have or can be used to answer those questions.

The first example is from the AgMIP wheat pilot project. A first study looked at the effect of climate changes that could occur in mid century on wheat yield in four locations, based on 26 crop models. The coefficient of variation of the simulated values was 20-30% depending on the location. This is a measure of the uncertainty in crop model predictions. In another study, each crop model was run with 16 different general circulation models (GCMs) for four locations, and the ratio of average yield in mid-century to average baseline yield wad calculated. Here the main interest was in the relative contributions of crop model uncertainty and GCM uncertainty. The individual contributions from the crop and climate models were estimated as the first order terms in the standard decomposition of total variance. It was found that the crop models have a much greater contribution to uncertainty than the GCMs. For example, for the Netherlands site, the CV associated with crop models is about 13%, compared to about 3% for the GCMs.

The second example is from a study underway on the uncertainty in predicting crop water use. Actual seasonal evapotranspiration (*ET*) can be written as $ET = (ET0)(\alpha)$ where *ET0* is potential evapotranspiration and $\alpha = ET / ET0$. The first order sensitivity coefficients, which can be evaluated from the multi-model results, allow us to apportion the variability between models to differences in potential evapotranspiration or to differences in α, and then to concentrate on the major source of the differences. This sensitivity analysis is possible because the simulation protocol called for each model to report both *ET0* and α. The possibilities of analysis are determined by the simulation protocol.

The third example is from a regional climate impact project. First, two rice models are calibrated using detailed experimental data from the region in question. Then, the models are compared to farm survey data and a bias correction coefficient is estimated. In a first study, the bias corrected models are used to calculate rice yield in other farms. What is the uncertainty in the results? In this study, a Bayesian Model Averaging (BMA) approach is envisaged. It is applied just to the last step. Thus the only parameters that are estimated for each model are the bias correction factor and the variance of residual error. Predictions are based on a weighted average of model predictions, where the weight assigned to a model is the marginal posterior probability of that model. The distribution of predictions indicates the uncertainty. Compared to the wheat pilot project, there are two main differences here. First, uncertainty derives not just from the differences between models but also from the residual error of each individual model. Secondly, the models are weighted by their posterior probability. In a second stage, we are interested in the uncertainty in predicting average baseline yield for each farm. This involves averaging over years. We can show that the variance of the predictions then depends on the correlation of errors between different years. In a third step, uncertainty in average future yield under climate change minus average baseline yield will be calculated.

These examples indicate the importance and diversity of uncertainty questions in AgMIP, and the use of multimodel ensemble results to address these questions. Future work will concentrate on comparing and evaluating different approaches to uncertainty analysis.

Keywords: *uncertainty, crop models, sensitivity analysis, Bayesian model averaging, climate change*

Using SIMULINK® to model and simulate supplier evaluation and selection problem

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Abstract: This paper presents a new conceptual model for supplier evaluation and selection decision support system using simulation. The model is based on the concept of Supplier Product-Profile Equivalent Cost (SPPEC) introduced previously by the authors. This paper intends to develop the previous model using simulation to generate a large number of suppliers' profiles that will enable a better and more accurate decision of best supplier based on a range of performance indicators.

Simulation is used to generate multiple values of the suppliers' performances summarised as an Actual Supplier-Product Profile (ASPP). In the process, each supplier has a range of different types of selection criteria (decision variables) that will change representing the supplier performance variations according to the process/product characteristics hence generating different numbers of scenarios of supplier-product performances which will then be converted into an equivalent cost named Supplier Product Profile Equivalent Cost (SPPEC) simplifying the task for the decision maker by selecting the supplier that generates the minimum cost; a simple, yet very powerful tool to use.

This methodology will produce a more realistic decision and will increase the confidence level in the decision making process. The basic simulation model is explained using an illustrative case where MATLAB® & SIMULINK® were used to build and simulate the model because of their strong computational capabilities and the availability of a wide range of tool boxes that can be easily and seamlessly integrated in the model.

The decision model can accommodate any number of criteria, any number of potential suppliers and any type of input data (qualitative or quantitative).

In addition to its simplicity, the interpretation of the results is straightforward. The use of equivalent cost to select the best supplier makes it more practical and easier to understand by any person in any industry.

It is also important to state that the model is a very flexible one. It can be tailored to suit any industry and to deal with any type of data. This may reduce the need to establish complicated and expensive data collection systems.

Another important advantage of this model comes from the wide range of potential applications; as it is very easy to utilise the concept in modelling and solving any multi-alternative decision problem. In further work, using Neural Network (NN) as a powerful learning tool may allow improving the existing model to learn from previous knowledge and potentially to utilise it in knowledge modelling and acquisition.

Keywords: *Supplier Evaluation & Selection, Simulation, MATLAB® & SIMULINK®, Multi-Criteria Decision System*

A model of idea generation, spin-offs and cluster formation

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Abstract: This paper will examine how patterns of industrial clustering arise with respect initial conditions, that is, both market structure and the fitness landscape of a given market. Through principles of evolutionary economics, and more specifically complex adaptive systems, the aim of this paper is to examine the 'birth' of industrial clusters. We take an endogenous approach, where firms in a region spawn from incumbents. Assuming the presence of habits and routines, we seek to model how the distribution and size of firms (within an industry and region) influence future patters of cluster formation. In addition to initial conditions, we allow for variability of select parameters; such as the frequency of interaction with other agents, critical thresholds for starting a new firm in qualitative and quantitative terms, the entropy of ideas, and, importantly, intra- firm, -industry and –region interaction frequencies as these frequencies depend on not only regional characteristics but also industrial cognition. We also account for heterogeneity using a code set, unique to a given idea, which represents an idea's characteristics, or phenotype. The aim is to seek out a 'critical mass' of cluster formation using these attributes. We then compare this structure with real-world phenomena using individual, geocoded patent data from Sweden.

Our eventual aim is to simulate the real-world phenomena that relatively large firms tend to higher quality firms, but spawn less frequently. Conversely, smaller firms tend to spawn more often but these tend to be firms of lower quality (when measured either in terms of profitability or the skill set of employees). Although prior empirical work has focussed on the incentives of a firm's employees (namely, tenure) as well as the higher industrial focus of larger firms, this paper will seek to explain spawning phenomena in terms of the heuristic nature of heterogeneous agents. While assuming that smaller firms have a smaller knowledge set of ideas, it is more likely that this set of ideas lies on a more limited range on the fitness landscape. This gives agents employed in these firms limited information of product quality. As agent's tend to employ rules-of-thumb when making economic decisions; the spread of idea quality, which is a function of the fitness landscape, has an impact on the final pattern of industrial spawning.

To capture this, we employ an Agent-Based Model (ABM) that leaves out as many assumptions as possible. We instead explore how real world phenomena can be explained through adjustable variables. The central idea of this paper is to model the complexity of cluster formation that is a result of the relative simplicity of the behaviour of the underlying agents. Our context of analysis is not employees, inventors or entrepreneurs. Rather, these entities act as vectors that carry ideas of a unique phenotype through Schumpeterian motivations. Results are measure through a derivative of a local Moran's I statistic. We then use this statistic to analyse final monopolistic structures of industrial clustering. Water plays a key role in the mining industry, mainly in supporting exploration and mineral extraction. Cost efficiency can be obtained by minimising the use of water. Efficient methods of water use minimisation during the recovery process are suggested to build on a framework for modelling and simulation of mine water use during dewatering. Dewatering can be described by a one-dimensional model for a thickener, centrifuge or pressure filter, where the local solids concentration depends on time and position.

Keywords: *Fitness landscape, industrial clustering, evolutionary economic geography*

An index of carcenogenesis using pairwise consistency

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Abstract: An index is developed for elements and molecules by applying pairwise consistency to relativistic quantum mechanics. This index can be applied to study carcinogenic substances identified in studies on humans or primates. This index is found to be significantly different between carcinogenic and non-carcinogenic chemicals tested on rhesus monkeys.

An existing theory of how some chemicals cause damage to living cells is that free radicals can react with other molecules to cause cell damage or DNA mutation. A free radical is any atom or molecule that contains unpaired electrons. Historically, this meant its spin was not zero.

In quantum mechanics each molecule under consideration can be thought of as a wave function from a Hilbert space. The Hilbert space of the wave function with odd half spin is shown not to be pairwise consistent. We have previously made the hypothesis that (the spaces of wave functions of) spin zero atoms or molecules are pairwise consistent.

Now the lens space $L\,(3,\,q)$ is also pairwise consistent if q is relatively prime to 3. Thus we reason that the latter may be a limit or generalization of the Hilbert space (of wave functions of the molecule under consideration). We have defined the above index based on a function that is sensitive to both spin parity and whether it is relatively prime to 3, the space dimensions.

The index can be used to extend the theory of how chemicals may cause damage to living cells. Based on the value of the index calculated from a molecule, that molecule can react with other molecules to cause cell damage or DNA mutation.

Keywords: *Carcinogen, pairwise consistency, representational consistency, quantum mechanics*

Simulation-based operational decision support systems

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Abstract: The complexity and interconnectedness of production and logistics systems produces a challenging environment for planners, operators and managers. In the operational environment, this is further complicated by uncertainty in data and process variability. The growing availability of time-based event and status data from historian databases creates the opportunity to apply predictive analytics and simulation technologies to improve operational performance. We report on recent progress and explore the value and challenges of deploying simulation-based decision support through a series of case studies selected from mining, manufacturing and logistics.

Real-time simulation models, which remain up to date and are capable of being used for 'look ahead' simulation during operation, have been integrated with decision support systems. These systems make use of the predictive and visualisation capabilities of discrete event simulation to allow decision makers to 'manage the present', produce robust schedules that are less susceptible to system variation and improve system resilience through fast recovery from disturbances.

We demonstrate that our approach enhances operational robustness. By generating schedules that can absorb uncertainty without causing resource or rostering conflicts, the need to reconfigure or reschedule is reduced. Probabilistic modelling of historical process variability allows schedule robustness to be estimated and evaluated against an acceptable risk threshold.

Prior to the occurrence of disruptions that exceed the risk threshold, simulation experimentation is employed to identify system states and operating strategies that make rapid recovery difficult. By avoiding these states or strategies, resilience can then be designed into the operation. When disruptions do occur, simulation-based decision support systems enable the rapid evaluation of responses, and support operational resilience through increase recoverability.

There exist theoretical and practical challenges relating to uncertainty of input data due to sensor noise and data recording. Algorithms to deal with incomplete, imprecise and incorrect data, which is often collated from multiple sources, are needed. Noise reduction and estimation techniques employed include simple moving average, Kalman filters, and advanced computational intelligence techniques, such as prediction interval-based forecasting.

The concept of a *history point*, a near real time 'state of the system' on which future planning can be made, is introduced. A history point serves to initialise the decision support system into the correct state, ready for the decision maker or operator to begin review, scheduling or what-if scenario analysis.

In the mining logistics case study, as well as automated estimates for each of the 500 plus variables used to construct the history point, autocorrect estimates, last history point value and manual override values are made available to the user. Historical process information is also needed to predict the operational performance of subsystems. For example, recent product type flow rates are used in the simulation to estimate future processing times.

A reconciliation process between scheduled events and historical schedules is required to synchronise systems and move the history point forward. In the mining case study, there was considerable variation between the scheduled train arrival time and the actual arrival time. These historical perturbations were used within the decision support system to test the robustness of the logistics plan to variability.

Keywords: *discrete event simulation, decision support system, robustness, resilience*

A Symmetry Analysis of Non-Autonomous von Bertalanffy Equations

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Abstract: In industrial applications involving microbial growth including food contamination, it is often the number of surviving microbes that must be modelled not the total population. For the total population N situation, the von Bertalanffy equation (von Bertalanffy (1957))

$$\frac{dN}{dt} = \alpha N^{\beta} - a N^{b}, \quad N(0) = N_0, \quad N = N(t), \tag{1}$$

has been a popular choice, because it models the situation as a competition between growth and decay. In addition, for various choices for the parameters α, β, a and b, analytic solutions are known which avoids the necessity to determine N using numerical methods. However, the morphology of its solutions is limited to being strictly monotonic increasing or decreasing, or asymptoting monotone increasing or decreasing functions. Consequently, this class of functions does not include functions which first increase, attain a maximum and then decay, which corresponds to the dynamics of the number N of surviving microbes in a closed environment. In order to model such situations as a single ordinary differential equation in N, the dynamics must be defined in terms of an appropriate non-autonomous ordinary differential equation with the non-autonomous terms taking account of the effect of the environment as well as the current size of the surviving population.

In a recent paper by Edwards et al. (2013), non-autonomous versions of the autonomous von Bertalanffy equation have been proposed to model microbial growth in a closed environment. The role played by the non-autonomous terms in this equation is discussed. The non-autonomous equation is extended here to include an additional non-autonomous term and a symmetry analysis has been used to study the structure of the solutions that such equations can generate.

Here it is shown how the non-autonomous von Bertalanffy equation can be reduced to an integrable equation for specific forms of the arbitrary functions.

Keywords: Autonomous, non-autonomous, ordinary differential equations, von Bertalanffy, symmetry analysis

Multi-level grade control in a mining supply chain DEM

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Abstract: A complex discrete event model was constructed to model an entire pit-to-port iron ore mining operation, including multiple mines, two rail lines and two ports. Inputs to the system included an 18-month block-level mine plan with estimated grades. The purpose of this model was to evaluate the trade-off between annual tonnes produced and grade quality, in the face of ore body depletion and changing customer requirements, in order to maximize tonnes per annum while minimizing any export grade penalties. The problem of managing ore grade with variability and uncertainty across the entire operation required the use of a global optimization, which calculated and updated a schedule of production every 24 hours of model time, with a look ahead of 30 days. The LP solver was integrated into the model code and acted as the intelligent driver of all ore handling activities. This approach allowed the evaluation of selected grade targets and production volumes in the context of an 18-month time horizon, including realistic operating conditions such as weather interruptions and equipment down times. The result was a dramatic reduction in export grade variability, with no loss of throughput compared to the case of no grade control. This work showed the feasibility of modeling the effects of grade control at an enterprise level, managing the variability and uncertainty inherent to any mining operation to achieve the best possible grade outcomes.

Keywords: *Discrete event model (DEM), Optimisation, Iron ore, Grade control*

Computational modelling of particle spray coating

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Abstract:

The precise control of coating deposition onto the surface of particles is a crucial batch process in industries such as food, pharmaceuticals and agriculture. Ideally, the coatings must be of a given thickness and be as uniform as possible. The coating must be thick enough to protect active ingredients within the particle against detrimental agents (such as oxygen and moisture), but thin enough to break down to deliver these active ingredients in a controlled manner. However, predicting the coating thickness and uniformity is difficult due to the complex nature of most batch coating devices. This is especially true in spray coating, where a fluidised bed of particles dynamically mixes with gas and spray droplets. Due to these difficulties, prediction of coating in such devices has typically relied on either rules-of-thumb, expensive experimental trial runs or simplified analytical models.

We present a comprehensive computational model for spray coating systems that combines particles, turbulent gas flow and spray droplets. Uniquely, the method tracks coating distributions over the surface of every particle in the system using a new incremental algorithm based on spherical harmonic expansions. These are the analogue of a Fourier expansion over a sphere, and allow a spherical function to be defined using a set of coefficients. Here, the coating depth over the particle is represented using spherical harmonic expansions. This has a number of advantages over representation of the coating depth in real space, including rotational invariance and the ability to quickly assess zonal coating distribution from the angular power spectrum. Although spherical harmonics have been used in a number of computational modelling fields, such as computational chemistry and biology, they have not previously been applied in this manner.

The dynamics of the particles are simulated using the Discrete Element Method (DEM), a Lagrangian approach for modelling granular materials in which the position and velocity of every particle in the system is individually resolved. The particles are coupled through drag relations to a computational fluid dynamic (CFD) model based on incompressible gas flow within porous media. The CFD method uses the Wall-Adapting Large Eddy (WALE) model to resolve the turbulent components of the gas flow. Spray droplets in the system are modelled as individual Stokesian particles. Any collisions between spray droplets and particles results in a splash pattern being mapped onto the surface of the particle. This splash pattern is based on realistic patterns from experimental scanning electron microscopy images. We show that these splash patterns can be efficiently mapped using spherical harmonic expansions, allowing a full time history of the coating deposition to be captured.

We apply the method to industrial fluidised bed spray coating systems, including bottom and top-spray fluidised bed coating set-ups. Functional relationships between system parameters, such as the gas fluidisation velocity and system geometry, and metrics such as coating coverage and coating uniformity are investigated. We show the computational model provides significantly greater predictive ability of such metrics over conventional approaches, as well as unparalleled detail on the individual, microscale, coating distributions within the bed.

Keywords: Spray coating, Simulation, Discrete element method, Spherical harmonics

Modelling of temporal combustion behaviour in a large-scale buoyant pool fire with detailed chemistry consideration

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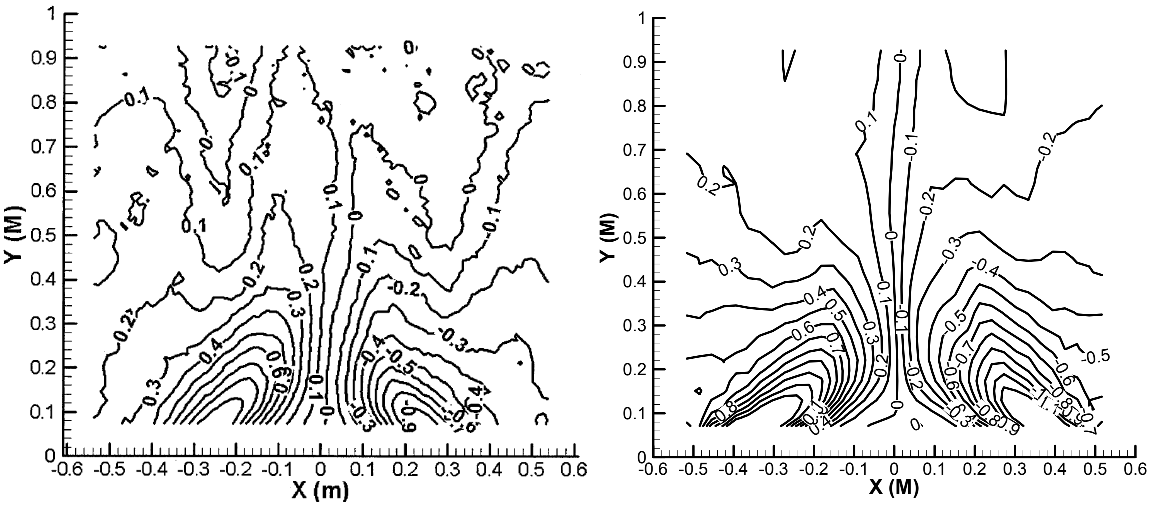
Abstract: Accurate prediction of the consequence of fire is crucial for fire safety analysis and assessment of designs for fire protection measures. Based on the previous study, a fully-coupled large Eddy simulation (LES) has been carried out to simulate the temporal combustion behavior of a large-scale buoyant pool fire. Although the pulsation effect of fire was properly captured, a single chemical reaction was adopted which could pose inappropriate interpretation of instantaneous heat release rate and vorticity generation. Combustion of fire involves hundreds of chemical reactions where the embedded kinetics plays a predominant role of the resultant heat release rate and species concentrations. Due to its complexity and intensive computational requirement, combustion kinetics simulations were used to be limited for combustion in laboratory scale. Most the existing fire models (e.g. Fire Dynamics Simulator – FDS) therefore only consider one or just few chemical reactions in simulation. With advancement of computer technology, integrating kinetics in fire modelling has become feasible. To investigate the influence of chemical kinetics on the vortical structures of fire, a LES model coupled with detailed chemical kinetics has been developed based on laminar flamelet approach. The flamelet library was evaluated based on the chemical mechanism for C1-C2 hydrocarbons combustion with soot formation. Numerical predictions are then compared and validated against previous numerical predictions and experimental data. Based on the preliminary results, the predicted time-averaged velocity and temperature profile has been found to be in good agreement with the experimental data whilst the temporal fluctuation of temperature and velocity are better captured in comparison to previous results with single step reaction.



Comparison of time-averaged horizontal velocity contour captured from PIV measurement of Tieszen et al. (2002) (left) and the present LES model (right) at the centre-plane of the fire

Keywords: *Large eddy simulation, Buoyant pool fire, turbulent combustion*

Simulation Of an Innovative Public Transport System

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Abstract: We report on the use of simulation in the design of in an innovative public transport system. We begin by giving a broad outline of an off-peak public transport system, being designed with the intention of a first implementation replacing weekend services in Canberra, Australia.

The proposed system is based on a small number of carefully selected *hub nodes* within the city. Hub nodes are linked by high-frequency bus service along trunk routes. A multi-hire taxi system is used to shuttle passengers between their origin or destination stop and the nearest hub.

In this paper we present the results of a simulation of this system. The simulation was run using actual travel data gathered from weekend bus use in Canberra. The simulation was used to test various design options, and helped to shape several aspects of the overall system design.

The main contribution of this paper is to explore the contributions to system design made using insights gathered from the simulation.

For example, contrary to expectation, we saw that a small number of nodes gave the best economic performance. We had expected that a larger bus network would allow the use of taxis to be minimised. However, a smaller number of nodes allows the demand to be concentrated better, allowing more effective use of taxis (higher occupancy).

Another early design feature that was overturned was the requirement that passengers are always shuttled to their closest hub. In some instances it is more efficient – both for the passenger and the taxi – to travel direct to the passenger's destination.

We discuss these and other aspects of the modelling and simulation of the system. We also present preliminary results of the simulations. The results show that for a real demand scenario in Canberra, Australia, the proposed system is able to achieve a one-third reduction in travel time over the current fixed-schedule bus system, without any increase in costs.

Keywords: *Public Transport, Multimodal, Demand-responsive*

Rim and tyre investigation for the in-wheel motor of an electric vehicle using simulations

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Abstract: Global demands for sustainability and compelling requirements to reduce environmental impacts have greatly influenced the transportation industry to look into ways to reduce carbon emissions. In recent years, electric vehicle (EV) development has taken a new paradigm due to environmental pollution, global warming and depletion of fossil fuels. Unlike automobiles with internal combustion engines (ICEs), EVs have intrinsic advantage of zero emission during operation, when used with renewable energy source for charging batteries.

To date most of the commercial EVs use permanent magnet motors (PMMs) due to specific low weight, and compact size (as it relies on use of permanent magnets for magnetic path). The key disadvantage of PMM is the need for rare earth elements, which also influence costs. To overcome the cost and availability issues associated with PMM, a new material or motor type is required to sustain EV growth. In this research alternative in-wheel (series mounting arrangement) switch reluctance motor (SRM) is designed which is fitted to a small car. The in-wheel SRM is selected due to specific advantages, i) use of non-rare earth element for magnetic path (stators and rotors), ii) low transmission losses (increased energy efficiency as it is direct drivetrain), iii) simplifies the design due to redundancy of mechanical systems (packaging of gearboxes, differentials, drive shafts and axles are not required, thus reducing the weight, cost and space requirements), and iv) increased ground clearance (due to redundancy of gear boxes and drive shafts). Small car provided substantial advantages with light vehicle weight, low power requirements, and enough mud guard clearances to implement in-wheel SRM.

In a wheel, the rim has typically been designed as a cylindrical metallic component, functioning as holder between car chassis and tyres. Tyres were added onto the rim perimeter, as a link between roads and rims, providing required cushioning effect. Consequently, in-wheel SRM EV had the intrinsic advantage of direct drive. However, this design increased the overall mass, as the wheel required an appropriate rim-tyre construction. Moreover, the in-wheel design with an SRM added further weight at the rear of the vehicle, changing its dynamics and performance. In this research, different rim-tyre models were analysed in context of an in-wheel SRM for developing the customised rim design and tyre selection. The suitability of the rim-tyre based on an in-wheel drivetrain required performance simulation pertaining to loads and dynamics at tyre-road interface. The rim selection was based on finite element (FE) simulation of five different sets. The standards and regulations for producing passenger car wheels in Victoria, Australia, were studied and successfully implemented in the development phase of this study. This paper describes the rim-tyre study conducted for in-wheel SRM. Starting with the rim optimisation, an appropriate tyre based on low rolling resistance was selected. The development of the rim-tyre configuration of the in-wheel SRM featured:

- Designing a rim for an in-wheel SRM design based on low unsprung mass and appropriate space that can accommodate motor, focusing on the rim size, shape and materials.
- Optimising rim topology by comparing different types of rims based on low weight characteristics for thermal and deflection simulations, as well as following recommendations for “Rim & Tyre Standards-Australia”.
- Tyre selection that meets two main objectives—low road resistance and clearance with mudguards—as well as detailed character mapping simulations to determine the appropriate tyre for the in-wheel design.
- Designing motor-to-wheel attachments, whereby making the wheel an integral part does not affect maintenance.

Keywords: *EV, In-wheel motor, rims, tyres and simulations*

Patient flow simulation modelling – an approach conducive to multi-disciplinary collaboration towards hospital capacity management

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Abstract: Emergency hospitals continue to face increasing demand and operate at high occupancy levels resulting in more frequent crowding and prolonged waiting. These issues are not expected to abate, but may become more frequent as hospital activity is predicted to increase.

Patient wait and crowding issues are outcomes that can be attributed to multiple causes. It will be important for hospital and health care managers to adopt new tools that will enable them to investigate the complex issue of patient flow through the emergency department and hospital in order to improve patient flow and minimise delays.

Simulation has been employed in various industries to achieve process improvement. Although simulation has been employed to investigate patient flow issues in health care its use as a routine management tool is yet to occur. The lack of up take of simulation may be attributed to a variety of factors including confusion about which methodology should be employed and the capacity to accurately model the complex health environment.

There are a variety of approaches to simulation including systems dynamic, discrete event and agent based modelling. Until recently off the shelf software packages enabled the modelling of systems using a single method. AnyLogic (anylogic.com) has been identified as a software package that enables a multi-method approach to be adopted and has been sufficiently proven in its use to warrant investigation as a tool to assist in the creation of simulation models of patient flow. The increased capacity of computers and the reduction in costs of both hardware and software are also no longer a barrier to the implementation of simulation as a means of investigating health care management problems.

The possession of modelling skills alone is insufficient to enable the development of a meaningful simulation patient flow model. Multi-disciplinary collaboration between a range of professionals is also required to enable the capture of the necessary information required to describe the hospital processes, analyse the data, create the and validate the model.

The aim of this project is to create an accurate simulation model of patient flow that accurately describes the progression of patients through the emergency department of a large teaching hospital into general medicine wards and then discharge. This paper describes the development of a concept for simulation modeling of the service and describes an initial model created by a multi-disciplinary team that will be used to investigate scenarios and strategies for improving patient flow through the hospital and reducing waiting times in the emergency department. The visual and quantitative outcome of this study will enable health care professionals and managers to understand the impact of their decisions on the hospital's operation efficiency as well as patient experiences.

Keywords: *Patient flow, simulation modelling, hospital capacity management, multi-disciplinary collaboration*

Adaptively limiting high order discontinuous Galerkin solutions to the advection equation

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Abstract: It is well-known that high order numerical solutions to conservation laws, such as to the advection equation, suffer from unphysical oscillations if a limiter is not implemented. However, implementing the limiter to high order numerical solutions, such as a discontinuous Galerkin solution, is very expensive computationally. Therefore, we propose an adaptive implementation of the limiter to the discontinuous Galerkin solution. That is, the limiter is implemented only on rough regions, as these regions are the actual places which need the limiter.

We focus on the advection equation as a representative of conservation laws with the following numerical settings. The boundary conditions are set to be periodic. The initial condition is set to include smooth and rough regions. Rusanov method, that is the local Lax–Friedrichs method, is used to compute numerical fluxes. Furthermore, weak local residuals are taken as the smoothness indicator to detect the positions where the limiter must be implemented and where the limiter is not needed. Note that this smoothness indicator was proposed by Karni, Kurganov, and Petrova ("Local error analysis for approximate solutions of hyperbolic conservation laws", Advances in Computational Mathematics 22(2005), 79–99 and "A smoothness indicator for adaptive algorithms for hyperbolic systems", Journal of Computational Physics 178(2002), 323–341).

We present some numerical simulations to show the effectiveness of our proposal. From our simulations, we obtain that solutions found by the adaptively implemented limiter on rough regions have the same order of accuracy as the solutions found by the fully implemented limiter over the whole domain. In addition, the run-time for simulations with adaptively implemented limiter is approximately the same as those without limiter.

Keywords: *adaptive limiter, discontinuous Galerkin method, advection equation, smoothness indicator*

Container packing problem for stochastic inventory and optimal ordering through integer programming

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Abstract: A supplier to a major manufacturing company is trying to cope with a probabilistic inventory management problem that has stochasticity in demand, material consumption rate, delivery times and other logistics-related parameters. Based on the specialized nature of the finished goods, the input materials are imported from Asia and carried in refrigerated containers that are subject to size and weight limits. The material should be used within a few weeks of receipt; otherwise the rate of manufacturing faults increases drastically. Unsatisfied demand (stockout) can be recovered expensively through the use of air transportation. The stochastic inventory problem with variable demand and lead time along with the optimal packing of containers are modelled as a stochastic optimisation problem. The solution to this problem expresses the optimal order size for raw materials considering all the stochasticities and other logistic limitations by minimizing the expected cost of stockout and over-supply. In addition, the optimal packing of pallets of raw materials into the containers is calculated simultaneously. In this paper, along with the modeling of the probabilistic inventory problem, we develop integer programming models for the optimal container loading and compare the numerical outputs.

Keywords: *Integer programming, stochastic optimisation, container packing, optimal ordering, stochastic in-ventory*

Impact of virtual training on safety and productivity in the mining industry

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Abstract: Best practice in the mining industry includes extensive initial and professional training for staff involved in field operations. While changes in mining technology and operations accelerate to improve productivity, health and safety standards have to be continuously evaluated and improved, putting more pressure on training deliveries. Borrowing from Defence and Airspace industries, training in the mining industry is increasingly relying on immersive virtual reality to simulate complex operations and procedures in potentially dangerous environments. Coal Services Pty Ltd is at the forefront of modern training facilities in Australia.

This paper presents a qualitative and quantitative research framework designed to analyse the impact of past and current training sessions on staff's ability to better perform their tasks, overall safety standards and mine productivity. It is relatively difficult to benchmark training techniques or programs in the mining industry as the very nature of the industry prevents from experimental comparisons with a control group. Hence, we have chosen to use diachronic methods to evaluate the effective impact of IVR-based training on worker's competences. In particular, our interviews with managers and access to relevant industry records will help us to identify two periods: before and after the introduction of IVR-based training. Another more qualitative approach will consist in interviewing personnel who have undertaken during their career at least two types of training programs, including IVR-based ones. The framework uses interviews with trainees, trainers and managers, alongside session recordings, to qualitatively evaluate levels of knowledge transfer and aptitudes to perform in a real environment. Then, a cost-benefit analysis is to be used to evaluate the added-value of virtual reality-based on technological and operational costs weighed against overall productivity of the mine being negatively affected by any safety issue.

Keywords: *Simulation, training, virtual reality, mining industry, safety*

EXTENDED ABSTRACT ONLY

Altering Typical Meteorological Years data to cater for Climate Change

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Abstract: Recent tragedies in Australia have demonstrated the need to adapt to severe unusual weather events. Increasing frequency and severity of heat waves have increased the mortality rates for the more vulnerable in the community. The problem is compounded by the prospects of higher energy costs and escalating peak electrical demand, as people become more reliant on air conditioning.

Houses constructed in 2012 to six star energy rating standards will most probably be still in use in 2030. Will the house still perform to six star standard with the expected changes in climate variables due to climate change? Note that if houses are designed to perform well in 2030 conditions, they will be more energy efficient during extreme periods in the present climate. The thermal performance of a house is evaluated using an appropriate software program such as AccuRate. The input for the analysis includes not only the house design but also a weather file containing a year's data for climate variables representing the expected conditions for the climate wherein the house will be built. This weather data file is referred to as a typical meteorological year (TMY). The 2007 CSIRO climate change report on regional impacts vis-a-vis climate variables provides the basis for the climate change alterations implemented in this study. The guidelines are provided in the form of projections of changes in the various climate variables at different probability levels. For instance, for Adelaide, there is a 90% chance that the mean temperature in summer will increase by at least 0.6°C, while only a 10% chance it will increase by 1.4°C or more.

The complicating feature that has to be taken into account is that the projected temperature alterations are not expected to be uniform in time. What is meant by that is that there is expected to be differential changes to minimum and maximum temperatures. There is also an expectation of more frequent extreme events. Previous work on altering climate data files includes that of Jentsch et al. and Guan. The former relies on the method developed by Belcher et al., wherein the process called `morphing' of data is used. This procedure involves a combination of shifting (translation) and stretching (dilation) of the separate climate variables to change their mean and variance. It does not take into account any differential translation, nor any cross correlation between variables. The procedure described by Guan on the other hand is more sophisticated, having similar attributes as above but also taking into consideration differential changes for minimum and maximum temperatures. The drawback of the method used is that the representation of the variation of temperature over the day is represented by a single sinusoid, unchanging over the year. Herein a more sophisticated Fourier model for both temperature and solar radiation is used. The solar radiation treatment is more sophisticated here as well, taking into account the three components of radiation, global, diffuse and direct. While Guan notes the cross correlation between solar and temperature, there is no indication that in the future series it is preserved. It should be noted that there are always pitfalls when dealing with data of unknown origin such as the data which was supplied for this project. We were forced to perform quality assurance analysis of the data which flagged flaws in the estimations of direct radiation that required remediation.

To facilitate the analysis we have developed new Typical Meteorological Year data sets for the Australian climate capital cities. These data sets utilise the climate change scenarios for A1B for 2030 projections as determined by the CSIRO. This data is constructed by altering the fixed stochastic component of temperature to accommodate the increase in the mean whilst also “bending” the data to reflect the different increase in maxima and minima. The solar radiation data is adjusted in a simpler way by increasing direct radiation to account decreased cloudiness and vice-versa and thus increasing global radiation. This process was location specific depending on the CSIRO discussion. This data could then be fed into AccuRate and the resulting energy usage interpolated to obtain values for 2050.

Keywords: *TMY, predictions, climate change*

Modelling Motor Vehicle Emissions and Population Exposure in South Australia

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Abstract: Motor vehicle exhaust has been identified as a dominant source of anthropogenic ambient atmospheric pollution. The greatest concentrations of traffic-related air pollution (TRAP) are emitted along heavily trafficked major roadways from which the associated detrimental effects of TRAP exposure have been well-established (HEI Panel on the Health Effects of Traffic-Related Air Pollution (2010)). Consequently, populations residing near major roadways have the greatest likelihood of potential exposure to TRAP and a high risk of experiencing adverse health effects.

We investigate pollution exposure levels for Adelaide residents in heavily trafficked areas by modelling and simulating TRAP emissions and movement in the atmosphere, with the development of an enhanced Link Emissions Modelling procedure for South Australia. The current Link Emissions Model (CLEM) for South Australia uses emission factors developed overseas and is based on a single average speed. The enhanced Link Emissions Model uses petrol passenger vehicle emissions and vehicle speed data from the second National In-Service Emissions study, to derive new Australian emission factors for use in South Australia. The result is the petrol passenger vehicle Link Emissions Model, PLEM. In essence, PLEM is an augmented version of CLEM, however provides the advantages of accommodating a range of vehicle speeds and is based on Australian data. The enhanced Link Emissions Modelling procedure for South Australia estimates road link TRAP emissions through the use of PLEM for petrol passenger vehicles in conjunction with CLEM for all other vehicle types.

The enhanced Link Emissions Model is implemented in a case study of selected densely trafficked roadways near residential areas of Adelaide, South Australia, to assess population TRAP exposure levels and the current air quality status in Adelaide. Vehicular exhaust emissions are estimated for each road link in the case study area using the enhanced Link Emissions Model. The Air Pollution Model (TAPM), an air quality tool for pollution dispersion, is used to analyse the movement of the link emission estimates in the atmosphere with pollution exposure maps showing approximate pollution concentrations for the case study region, generated by combining TAPM output with Geographic Information Systems data. Results of the case study indicate that TRAP concentrations are greatest over main roads and their intersections, with pollutant concentrations declining with increasing distance from the main roads. Pollution concentrations fluctuate across the week, with each day typically experiencing two peaks in air pollution concentrations corresponding to peak traffic hours. The lowest pollution concentrations occur during the early hours of a day when traffic volumes are typically lowest. Furthermore, the results suggest TRAP concentrations are subject to seasonal variation with the greatest concentrations occurring during the calm, cold weather conditions of winter and the lowest concentrations occurring during the windy, warm summer season. Atmospheric vehicle exhaust pollution concentrations in the case study area of Adelaide are comfortably below the threshold levels specified by the World Health Organisation however Adelaide residents are exposed to a notable volume of vehicular exhaust pollution. Thus mitigation strategies for TRAP emission and exposure should be designed and implemented for South Australia.

The case study results indicate use of the enhanced Link Emissions Model provides a strong understanding of approximate pollution concentrations in the Adelaide air shed, forming a solid platform upon which to base future informed strategies for emission reduction and exposure mitigation.

Keywords: *Motor vehicles, emissions, pollution, dispersion, exposure*

On Factory Relocation via Integer Programming

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Abstract: This paper gives a case study of a manufacturing firm that seeks to move its' plant location from a higher cost manufacturing base to one of lower costs. As US companies face increasing competition in the global marketplace, they are continually on the lookout for cost reduction opportunities. Frequently this involves a new plant location decision to another country or another state where labor costs are lower. In this case, the company located on the east coast of the US had settled on a new location along the Mexican border but still within the US. The decision facing the company was a strategic one of whether to move to the new location or not.

The company manufactures rubber seals of multiple types on various production lines each of which requires certain skill types to run efficiently. Consequently if all the lines were not moved at the same time, there was a technology induced order in which the lines could be moved to allow time to assimilate skills at the new location. Movement of production lines was also constrained by plant closing laws and environmental considerations. In this case, a law called the WARN act applied which restricted the company to laying off no more than one third of its' work force in any three month period. The manufacturing process produced ground contamination which would require immediate remedial action if all the production lines were moved.

Several costs are involved in the movement decision. First there is the reduced manufacturing cost at the new location. This is represented in the model as a savings per month once a production line is operational at the new location. Clearly there is a cost associated with laying off workers. We allow for the possibility that the company will pay idle workers in order to conform with the WARN act. Finally there is a significant clean-up cost if the company moves all production lines; this cost is not incurred if all lines are not moved to the new location.

The decision problem is to maximize total savings minus cost over a finite time horizon while meeting the technological constraints on the order of moving production lines, constraints imposed by the WARN act and finally the environmental constraint if all lines are moved. The decision variables are essentially which production lines are moved to the new location and the timing decision of each move. This is modeled as an integer program, which being of relatively low dimension is readily solved by commercial software. In our case, we used AMPL/Cplex.

The model was then used to determine a move strategy for the company and to explore a number of what-if scenarios. In the US, a strategic decision of this nature involves union and political issues as well as financial ones. Although our model only captures the latter, it proved extremely useful in negotiations with the union representing workers in the current plant. Exactly what happened will be outlined in the talk.

Keywords: *Factory Relocation, Integer Program, Union*

Analysis of Queuing Scheduling Linkage Model to Minimize the Hiring Cost of Machines/Equipments

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Abstract: Hiring of machines/equipment is growing as the most preferred alternative method for financing the latest technology in many developing countries due to budgetary constraints faced by most of industries. The present paper is an attempt to develop an algorithm to minimize the utilization time of machines/equipments taken on rent and hence their hiring cost for the proposed queuing scheduling linkage model. The phase I of service (network of queues) consists of parallel and biserial servers in which the arrival and the service pattern both follows poisson's law. Further, the completion time of jobs in getting phase I of service will be the setup time for first machine in phase II of service consisting of '*m*' machines/equipments in series taken on rent. In industries men, machines, materials and money are involved for production. The manager of an industry is interested to use them in an economic manner so that the cost associated with the production is not increased or it minimum in the competition market. In industry there are some very complicated machines that are often necessary for performing a variety of procedures. In order to stay competitive, up to date equipments are required and buying all of these equipments get really expensive over time. There are industries who take various machines/equipment on rent and hiring of equipment is an affordable and quick solution for many industries, which are presently constrained by the availability of limited funds due to the recent global economic recession. Renting of equipments/machines enable saving working capital, give options for upgradation to new technology. The objective of paper is to find the latest time at which machines/ equipments should be hired so as to minimize utilization time and hence their hiring cost with minimum total elapsed time and with minimum mean queue length for the proposed queuing scheduling linkage model. A numerical illustration is also carried to test the efficiency of the proposed algorithm.

Keywords: *Flowshop scheduling, Mean queue length, Utilization time, Waiting time, Hiring Cost*

An Environmental and Economic Performance Measure for Industrial Supply Networks

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Abstract: This paper aims at establishing a quantitative measure for economic and environmental Performance of industrial supply networks. To the best of the author's knowledge, this measure is the only one that considers aleatory and epistemic uncertainties in its environmental performance evaluation. The measure is built upon economic and environmental performance evaluation models. These models address identified shortcomings in the literature such as incomplete and inaccurate calculation of environmental impacts, as well as the disregard for aleatory and epistemic uncertainties in the input data. This measure provides an approach to quantify the environmental and economic performances, and accordingly the sustainability performance, of the supply network. Moreover, as this measure is not specified for an industrial sector, it can be employed for initializing a dialogue between members of supply networks about their sustainability performance. This can lead into an establishment of sustainability databases that are useful for both the network members and researchers. The measure does not account for the social component of sustainability. This is due to the lack of information about social aspects of organizations and hence their supply network. Moreover, as organizations have no strategies in place to collect information relevant to the supply chain, data for the demonstration of the method is not accessible to the researcher. Thus, the implementation of the model in a real world scenario is left for future studies upon the completion of data collections. The measure is based on ratio indicators that facilitate the comparison between current and future performances. This facilitates creating a set of sustainability targets necessary for establishing a sustainable management system within an organization. Moreover, the measure provides information to the process manager about the relationship between environmental safety decisions and the process's profit, when the process is a part of a supply network. Furthermore, this measure provides a common language for the companies to extend their individual sustainability targets toward the whole supply network.

Keywords: *Conceptual Model, Dyadic, Environmental Performance, Industrial Sector, Profit, Reliability, Revenue sharing, Supply Chain Performance*

Data-driven Modelling and Analysis of Household Travel Mode Choice

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Abstract: One of the important problems studied in the area of travel behaviour analysis is travel mode choice which is one of the four crucial steps in transportation demand estimation for urban planning. State of the art models in travel demand modelling can be classified as trip based; tour based; and activity based. In trip based approach, each individual trips is modelled as independent and isolated trips i.e. no connections between different trips. In tour based approach, trips that start and end from the same location (home, work, etc) and trips within a tour are dependent on each other. In past two decades, researchers have focussed on activity based modelling, where travel demand is derived from the activities that individuals need/wish to perform. In this approach, spatial, temporal, transportation and interpersonal interdependencies (in a household) constrain activity/travel behaviour.

This paper extends tour-based mode choice model, which mainly includes individual trip level interactions, to include linked travel modes of consecutive trips of an individual. Travel modes of consecutive trip made by an individual in a household have strong dependency or co-relation because individuals try to maintain their travel modes or use a few combinations of modes for current and subsequent trips. Traditionally, tour based mode choice models involved nested logit models derived from expert knowledge. There are limitations associated with this approach. Logit models assumes i) specific model structure (linear utility model) in advance; and, ii) it holds across an entire historical observations. These assumptions about the predefined model may be representative of reality, however these rules or heuristics for tour based mode choice should ideally be derived from the survey data rather than based on expert knowledge/judgment. Therefore, in this paper, we propose a novel data-driven methodology to address the issues identified in tour based mode choice. The proposed methodology is tested using the Household Travel Survey (HTS) data of Sydney metropolitan area and its performances are compared with the state-of-the-art approaches in this area.

Table 1. Classification of state of the art approaches in mode choice

Data Type / Trip Type	Discrete Choice Models		Machine Learning	
	Crisp Data	**Crisp & Fuzzy Data**	**Crisp Data**	**Crisp & Fuzzy Data**
Independent Trips	Gaudry, (1980); McFadden (1973); Daly & Zachary (1979); Hensher & Ton (2000)	Dell'Orco *et al.* (2007)	Xie et al. 2003; Reggiani & Tritapepe 1998; Cantarella et al., 2003; Shmueli et al. 1996; Edara 2003; Hensher and Ton, 2000	Yaldi, G. (2005)
Linked Individual Trips (tour-based)	Miller et al. (2005)	-	Biagioni et al., (2008)	This Study
Linked Household Trips	Miller et al. (2005)	-	Future Work	Future Work

Keywords: *Travel mode choice, data mining, travel mode choice, fuzzy sets*

Multiplicity in combustion wave behaviour for a model with competing exothermic reactions

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Abstract: Combustion, while being part of our everyday experience, is a complex phenomenon involving a multitude of reactions and dynamics. There is great value in understanding combustion through mathematical modelling, not only for its own sake, but also because of the applications of the developed model to combustion-based industrial processes or to that perennial environmental threat to populace, property and wildlife — the bushfire.

In this work, we present a mathematical model of a combustive process where the combustion wave propagates through a fuel shaped like a rod, as it may be in self-propagating high temperature synthesis of metals. Said fuel is assumed to have chemical properties such that all reactions occurring during combustion may be lumped together as two different heat producing (exothermic) reactions. The model presented considers the idealised case of there being no heat lost in the reactions (i.e. the adiabatic limit).

The two reactions, say A and B, compete for the available fuel. In one limit of the model parameters A will dominate and consume the majority of the fuel. At another extreme reaction B will dominate. In both cases our model reduces to the well-known "one-step" model. The one-step model allows a single wave front solution per system parameter.

At intermediate parameter values no reaction dominates to the complete exclusion of the other. We argue there must exist some parameter value at which reactions A and B are consuming the fuel equally. Either side of this "cross-over" point one reaction begins to dominate. The "cross-over" concept enables the determination of the region in parameter space that allows a multiplicity of solutions. That is, for a given activation energy, there are multiple allowable combustion waves which typically have large differences in propagation speed.

Lastly, the boundary for the transition from unique solutions to multiple solutions is calculated numerically and it is demonstrated that within this multiplicity region the flame front speed is an 'S'–shaped function of the model parameters.

Keywords: *Combustion waves, competitive reactions, multiplicity*

The aggregate association index and its links with common measurements of association in a 2x2 table: An analysis of early New Zealand gendered voting data

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Abstract: The analysis of aggregate, or marginal, data for contingency tables is an increasingly important area of statistics, especially in political science and epidemiology. Aggregation often exists due to confidentiality issues or by source of the data itself. Aggregate data alone makes drawing conclusions about the true association between categorical variables difficult, especially in dealing with the aggregate analysis of single or stratified 2x2 contingency tables. These tables are the most fundamental of data structures when dealing with cross-classifying categorical variables hence it is not surprising that the analysis of this type of data has received an enormous amount of attention in the statistical, and related, literature. However, the information, from which the aggregate data can provide for the inference of association between the variables, is still a long standing issue. In order to analyse the association that exists between the variables of a 2x2 table, or stratified 2x2 tables, based only on the aggregate data, numerous approaches that lie within the area of Ecological Inference (EI) have been proposed. As an application of this new development, we shall analyse a unique record of New Zealand gendered election data from 1893 when it was the first self-governing country in the world allowing women to vote, this trend quickly spread across the globe. Since the NZ data structure consists of stratified 2x2 tables, where the stratifier is electorate, the issue of analysing a single 2x2 table shall not be discussed. For stratified 2x2 tables, a number of ecological inference techniques exist but these rely on strong, yet untestable assumptions, which are not applicable to a single 2x2 table. To remedy this, one may analyse the association between two dichotomous variables, given only the aggregate data, by using the Aggregate Association Index (AAI). To date, the AAI has been expressed as a function of a conditional probability and been used to test if a statistically significant association is likely to exist given only aggregate data. Nevertheless, the interpretation about the strength and direction of association cannot be obtained through the current AAI. As a result, the purpose of this study is to broaden our understanding of the AAI by establishing its functional link with other classical association measurements, such as the standardised residual, Pearson's ratio, contingency and correlation indices. For brevity, only the standardised residual shall be considered here as a foundational baseline for the other association measures. This work will allow us to confirm the characteristics of the AAI's generalizability and enable analysis of aggregate data in terms of common association measurements. In other words, we show that the analysis of aggregate data of the 2x2 tables can be extended from justifying the existence of an association to that of determining the strength and direction of the association, if it exists, given only aggregate data. The important nature of association between gender and voting in the election shall be carefully examined given only aggregate data and compared to the information from a complete data analysis reported in (Hudson, Moore, Beh and Steel, 2010). Moore (2005) confirmed that gender was a significant factor in determining voting in early New Zealand elections from 1893. This paper shows that the AAI can provide the same result for testing the statistical association between the two dichotomous categorical variables, voting and gender, irrespective of the association measurements considered, and given only the aggregate data, or marginal information, of a 2x2 contingency table. It is noteworthy that, it is also possible to establish a relationship between the traditional AAI with other association measurements such as the standardised residual, so as to obtain a better understanding of association in terms of strength and direction. This new development thus extends the application of the AAI from not only justifying the existence of association, but also to interpretation of how strong or weak the association is and which direction (positive or negative) it is likely to be. Future developments of the AAI will involve the formulation of how to combine multiple AAI (Z_g) curves from each electorate into a single index for an election year. This may well allow us to compare the trends between politics and gender among different NZ elections (from 1893 to 1919) and to provide a better and unique methodology for ecological inference.

Keywords: *Aggregate Data, Aggregate Association Index (AAI), 2x2 tables, ecological inference, standardised residual, New Zealand election*

Sport Synthesis: using simulation models to understand incentives for sporting teams to tank

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Abstract: Annual draft systems are the principal methods by which teams in major sporting leagues recruit amateur players. These draft systems frequently take one of three forms: a lottery style draft, weighted draft, or a reverse-order draft. Major sporting bodies such as the National Football League (NFL), National Basketball Association (NBA), Major League Baseball (MLB) and the Australian Football League (AFL) have adopted player recruiting systems whereby the best amateur players in a particular year are chosen by clubs in reverse order to their finishing position in that year. Reverse-order draft systems have the benefit of allowing clubs with the poorest win-loss record in a season access to the most highly-rated amateur players. Consequently, low-ranking clubs gain the best opportunities to improve their player lists and increase the likelihood of on-field success. Controversially, reverse-order drafts can create incentives to deliberately under-perform, or tank, due to the perceived gain from obtaining quality players at higher draft picks.

This paper uses a dynamic simulation model – Sport Synthesis – to capture the key components of a win-maximising sporting league, such as the AFL. The model is akin to those currently used to simulation test alternative management strategies for natural resources, such as fisheries. Many of the properties of natural resource assessments are easily transferable to sporting players and their competitions. For example, fish are born, grow in size, and eventually are either caught or die of natural causes. Similarly, a sportsperson is recruited to a club, grows in ability, and eventually retires or is delisted. Fisheries and sporting leagues are both examples of complex dynamic systems – ideally suited to stochastic simulation modeling to explore their characteristics and evaluate alternative management strategies.

Sports Synthesis incorporates parameters to describe an amateur player draft, draft choice error, player ability, and between-team competition. Together these components permit an exploration of how competitive balance (the equalization of success across teams) and incentives to under-perform differ according to league characteristics. The model is used to test the propensity of draft systems, such as lotteries and reverse-order drafts, to generate incentives for teams to tank. A simulation is initialized with each team receiving players of varying ability, assigned according to their draft number, age, and an error term reflecting a club's ability to successfully select quality players. Each simulated year, teams are ranked according to their overall team strength, a premiership order is determined, players are de-listed at the end of the year, and teams enter a draft where they obtain new players according to the specified draft system. Player ability is then updated and a new year or season begins. To simulate tanking, teams adopting a tanking strategy have their team productivity (or strength) reduced relative to other teams when they are unlikely to make the finals. This potentially lowers a team's position on the premiership table, and can lead to better draft picks (e.g. with a reverse-order draft).

Model results indicate reverse-order drafts can lead to some teams cycling between success and failure and to other teams being stuck in mid-ranking positions for extended periods of time. We also find that an incentive for teams to tank exists, but that this incentive decreases (i) as uncertainty in the ability to determine quality players in the draft increases, (ii) as the number of teams in the league reduces, (iii) as team size decreases, and (iv) as the number of teams adopting a tanking strategy increases. We also find that, of the draft systems tested, reverse-order drafts provide the greatest incentive for teams to tank, and that a combination of draft types may provide the best overall system for reducing incentives to tank while maintaining competitive balance.

Keywords: *Player draft, simulation model, competitive balance, player productivity, tanking*

Derivative Spectroscopy and Sparse Regularization

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Abstract: In a way, for NIR spectroscopy data, "derivative spectroscopy" performs a type of "sparse regularization" (not necessarily L_1) procedure in that it identifies places were rapid changes are occurring and highlights features in the observed spectrum which are not necessarily visible by eye. The extent to which this fact be formalized algebraically is the goal behind related research.

For the solution of an underdetermined system of linear equations (such as the NIR spectroscopy equations)

$$A\beta = \mathbf{p}, \qquad A \in R^{m,n}, \qquad m < n, \tag{1}$$

"sparse regularization" corresponds to performing the following constrained minimization

$$\begin{aligned} & \min \|\beta\|_0 \\ \|A\beta - \mathbf{p}\|_* \quad \leq \quad & \delta, \qquad 0 < \delta << 1, \end{aligned} \tag{2}$$

where $\|\beta\|_0$ denotes the number of non-zero elements in β and $\|.\|_*$ a norm that is appropriate for taking account statistically of the measurement errors in $\|\mathbf{p}\|$.

In order to avoid the computational complexity associated with performing the minimization (2), especially when A is highly underdetermined with $m << n$, alternative approximation procedures have been proposed, analysed and implemented. The prototypical example is the replacement of the minimization (2) with L_1 minimization

$$\begin{aligned} & \min \|\beta\|_1 \\ \|A\beta - \mathbf{p}\|_2 \quad \leq \quad & \delta, \qquad 0 < \delta << 1. \end{aligned} \tag{3}$$

The regularity under which the minimization (3) yields an accurate and computationally efficient estimate $\hat{\beta}$ of β has been examined in detail by various authors.

The approach investigated here is to show that, like L_1 regularization, the numerical differentiation of spectroscopic data (derivative spectroscopy) can be viewed as an approximation procedure for solving the sparse regularization minimization (2). It is limited to situations, such as NIR spectroscopy, where the values in the rows of A represent accurate realizations of the actual values of the underlying signal discretized on a very fine grid.

The goal is the identification of the regions in the spectra which contain essentially no information about the material under investigation. In the associated linear system, this information is mapped into the structure of the solution β by insert zeros into the appropriate locations. The possibility of utilizing the explicit and implicit spiking methodologies of Anderssen, de Hoog, Wesley and Zwart is examined.

Keywords: *derivative spectroscopy, sparse regularization*

Sparse regularization of NIR spectra using implicit spiking and derivative spectroscopy

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Abstract: For the application of spectroscopic calibration and prediction (CAP), the data consists of measurements, for each sample in some representative set, of both the property of interest and a spectral encapsulation (e.g. for wheat samples, their glutenin contents and NIR spectra). The information in the spectra about the property is confounded by the other components in the samples (e.g. in wheat, the gliadin) since their proportional presences also change. Nevertheless, one has an *implicit spiking* situation in the sense that one knows the ordering of the proportional presence of the target property (e.g. the gliadin). Here, using glutenin and NIR spectra for wheat, the extent is examined to which the explicit sparse regularization protocol developed by Anderssen, de Hoog, Wesley and Zwart for milk powder samples spiked with casein can be applied in a CAP analysis of implicitly spiked data.

An often occurring situation in information recovery arises when the indirect measurements of the phenomenon of interest (an NIR spectrum of milk powder; an image recorded on a very high resolution CCD camera) contains two different phases: (i) the information which encapsulates the answer to the question under examination (the proportional presence in milk powder of the casein, the major protein component; a lower resolution image is all that is required) and (ii) a considerable amount of superfluous information, the presence of which compromises the reliability with which the question can be answered. In such situations, for the identification of the information that encapsulates the answer, *"sparse regularization"* and *"compressive sensing"* are widely utilized. From both theoretical and practical perspectives, though there is an overlap between these two methodologies, their basic *modus operandi* are different. The former is more suited to spectroscopic data applications, where the scientific basis for the structure within the data is known, while the latter plays a key role in image and data compression and sensor network applications, where often there is no rationale for the structure in the data other than the circumstances of the application.

In this paper, the focus is the application of sparse regularization to the analysis of near infrared (NIR) spectroscopic data. It has already been shown Anderssen et al. (2013) how the explicit spiking of biological data can be used to identify, in the corresponding NIR spectra, the wavelength bands associated with the spiking that are essentially independent of the other components in the sample. In particular, this was done using samples of the same milk powder explicitly spiked with known different amounts of casein and derivative spectroscopy to perform the sparse regularization. The goal in this paper is to give independent validation to the methodology developed for the milk powder situation Anderssen et al. (2013) and thereby establish that it extends to CAP data where the spiking is implicitly determined by the chosen samples. This is achieved by applying the derivative spectroscopic sparse regularization to the NIR spectra of individual wheat grains for which the different levels of the proteins gliadin and glutenin have been measured.

The essence of the explicit spiking methodology, on which the milk powder analysis was based, is the identification of the wavelengths at which the intensities of the spectra correlate strongly with the proportional presence of the target property. The underlying assumption/rationale is that they represent the locations in the spectra where the interaction of the target component with the other components in the sample are minimal.

The paper has been organized in the following manner. As motivation for the implicit spiking approach, the explicit spiking methodology is reviewed in Section 1. Relevant details about the structure of NIR spectra, and, in particular, the wheat spectra analysed, are discussed in Section 2. The results of the spiking analysis of NIR wheat spectra, for which the proportional presences of albumin, gliadin and glutenin were available, are presented and discussed in Section 3.

Keywords: *Calibration and prediction, spiked data, near infrared spectroscopy, single grain analysis*

A first approach to resolving ambiguity in hidden terrorist group detection in communications networks

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Abstract: One of the most challenging problems in detecting terrorist groups in communications networks is that of identity ambiguity. Node identification mechanisms for modern communications networks can range from a mobile phone number to an email address, IP-address or VoIP account name, meaning that terrorist group members can easily assume a new network identification or possess multiple identifications simultaneously. To compound matters, terrorists are also known to employ sparse pseudorandom communication patterns while maintaining constant connectivity between group members. We are interested to address the issue of correctly identifying members of a hidden terrorist group after a change of identification has occurred.

We propose a method we call *implied connections* as a first approach to resolving such ambiguity. We begin by collecting connectivity information over an m-size neighbourhood for each node in a network over a specified observation period. This information is then converted to a weighted graph of unobserved but potential relationships between nodes we call implied connections.

The method of implied connections is tested on two real-life dynamic networks derived from mobile phone and Internet traffic data consisting of approximately 10,000 and 2,000,000 unique nodes respectively. For each network type we construct two graphs of implied connections to capture network characteristics of interest before and after a suspected change of identification has occurred. We then adapt a method of inexact subgraphs similarity and calculate β-signatures for both the subgraphs of implied connections of the network member with a new identity as well as potential candidates for the original network identity. As such, a β-signature is calculated as a column vector of probabilities of the next connection of a chosen network member to any other member of their m-size neighbourhood.

Following calculation of the β-signatures, we find the best match between subgraphs of implied connections based on Euclidean distance as defined in the multi-dimensional space of the subgraphs members. Individuals whose subgraphs are of higher similarity, that is, have shorter a distance between their β-signatures, are considered more likely to be the same person.

Our results indicate that an analysis of implied connections improves the characterisation of the relationships between nodes and substantially increases the probability of correctly identifying members of the terrorist group after an identity change has occurred.

Keywords: *Hidden network, ambiguity, implied connections, dynamic graph series*

Deriving soil hydraulic properties at an intermediate scale using the cosmic-ray neutron soil moisture probe: An inverse problem

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Abstract: The cosmic-ray neutron soil moisture probe is a relatively new measurement device which provides measurements of soil moisture over a circular area with a radius of approximately 335 m (~40ha). Continuous measurements are derived from depths varying from <0.1 m for wet soil to 0.8 m for dry soil. This instrument gives a continuous time signal of the depth weighted moisture content ($\bar{\theta}$) given by $\bar{\theta} = \int_0^{z^*} W(z).\theta(z)dz \,/ \int_0^{z^*} W(z)dz$ with $W(z) = a[1 - z/z^*]$, $0 < z \le z^*$ and the effective depth of measurement (z^*) given by $z^* = 5.8/[\rho_b\tau + \bar{\theta} + 0.0809]$ with ρ_b the bulk density of the soil (kg m^{-3}) and τ the bound or lattice water content. This is a measurement of a state variable of the soil system ($\bar{\theta}$), what we want to determine are the water fluxes in the soil as these fluxes can be related to the hydrological properties of the soil. Two properties of interest are infiltration rate and the saturated hydraulic conductivity (Ks - m s^{-1}) of the soil. Infiltration of water into a soil at an initial water content of θ_i will occur at the applied surface flux of water, j (m s^{-1}), if this is < the infiltration rate capacity of the soil, i_c (m s^{-1}). However, once $j > i_c$ water will start to pond on the surface and the infiltration will be controlled by i_c. With time, as the wetting front moves deeper into the soil and hence capillary effects on infiltration become negligible and $i_c \rightarrow Ks$.

We analysed data from a cosmic-ray neutron soil moisture probe installed at Weany Creek in north Queensland (-19.88S, 146.54E) for the period between February 2010 and January 2012. During wetting events j was estimated from the difference between rainfall and potential evapotranspiration. The cosmic-ray neutron soil moisture probe also measures water ponded on the soil surface; ponding was estimated by identifying when $\bar{\theta} > \theta_s$, where θ_s is the saturated water content (= 0.37 m^3 m^{-3}). The detention depth of water, d, on the surface can be estimated by $d = \bar{\theta} z^* - \theta_s z_m$, and z_m is $z^*(\theta_s)$. The maximum detention capacity estimated was 5.4 mm. The penetration depth of the wetting front, λ (m), can be estimated by $\lambda = I/(\theta_s - \theta_i)$ where I is the cumulative infiltration. Estimation of Ks is only possible when $\bar{\theta} \ge \theta_s$ and $\lambda > z^*$. During the study period there were 54 rainfall events which provide 90 data individual estimates of Ks. Some of these data points where Ks is > 10 mm hr^{-1} were eliminated, as they occurred at the start of the rainfall event and are influenced by sorptivity. This results in a mean value for Ks of 4.2 mm hr^{-1} which is much less than the published value for this location (~30mm hr^{-1}) but provides runoff estimates consistent with those measured at this site. The strength of the cosmic-ray neutron soil moisture probe is its ability to provide continuous spatially averaged soil moisture data over an area of ~40ha. At such a scale much of the variability observed for small scale measurements is overcome, hence deriving soil hydraulic properties based on such data results in parameter values more closely matched to that of landscape scale models.

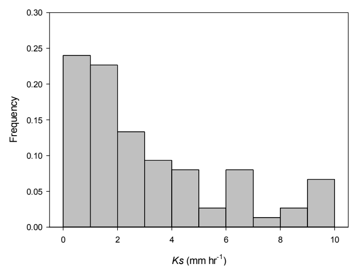

Figure 1. Frequency of *Ks* values derived for Weany Creek using the cosmic-ray soil moisture probe.

Keywords: *Saturated hydraulic conductivity, Cosmic-ray neutron soil moisture probe, runoff, detention capacity*

Density Estimation via Optimal Control

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Abstract: We consider the problem of estimating the probability density function $f : [0,1] \to \mathbf{R}$ by the function $f_v : [0,1] \to \mathbf{R}$ such that

$$f_v(t) = e^{v(t)}, \quad \text{with} \quad \int_0^1 e^{v(\tau)}\, d\tau = 1, \tag{1}$$

where $v : [0,1] \to \mathbf{R}$ solves the problem

$$\text{(P)} \quad \min_{v(\cdot)} \frac{\alpha}{n} \int_0^1 \dot{v}^2(t)\, dt + \frac{\alpha\beta^2}{n} \int_0^1 (v(t) - w(t))^2\, dt - \frac{1}{n} \sum_{i=1}^{n} v(t_i),$$

and t_i, $i = 1, \ldots, n$, are points sampled from an unknown distribution. Here, w comes from a known distribution; α and β are referred to as the smoothness and structure parameters, respectively. The last term in the functional pertains to maximum likelihood.

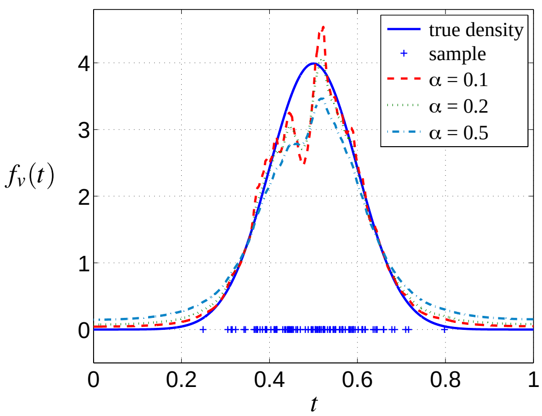
If one re-formulates Problem (P) as an optimal control problem and applies a maximum principle for optimal multi-processes, Problem (P) reduces to one of solving the following two-point boundary value problem. The function v in (1) solves

$$\ddot{v}(t) = \beta^2 (v(t) - w(t)) + \gamma e^{v(t)}, \quad \text{for all } t \in (t_i, t_{i+1}),\ i = 0, \ldots, n, \tag{2}$$

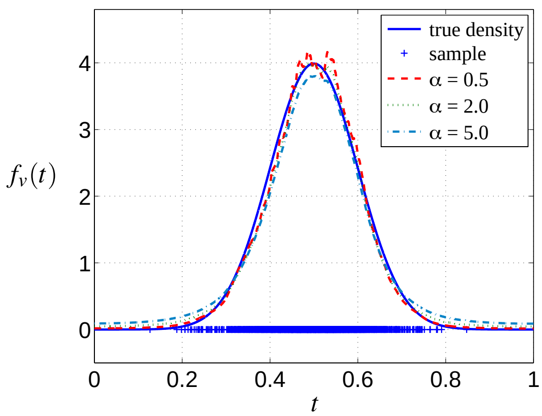
$$\dot{v}(0) = 0, \quad \dot{v}(t_j^+) = \dot{v}(t_j^-) - \frac{1}{\alpha}, \quad j = 1, \ldots, n, \quad \dot{v}(1) = 0, \tag{3}$$

where $t_0 = 0$ and $t_{n+1} = 1$, and γ is a real constant. Note the jumps, given in (3), at each of the sample points.

We display below the graphs of the solutions of the trapezoidal rule discretization of (2), along with (3), for various sizes of sampling from the normal distribution with mean 0.5 and variance 0.01, for $\beta = 1$ and various values of α.



(a) 100 sample points



(b) 2000 sample points

***Keywords*:** *Density estimation, multiprocess optimal control, two-point boundary-value problem, numerical methods.*

Correcting for finite probe diameter in the dual probe heat pulse method of measuring soil water content

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Abstract: This paper provides a simple correction to the measurement of soil volumetric heat capacity (and soil water content) using a dual probe heat pulse device with instantaneous heating, to allow for rods of finite radius and heat capacity. The correction is based on the spatial weighting function of Knight *et al.* (2007) and checked using the identical cylinders perfect conductor (ICPC) theory of Knight *et al.* (2012).

The dual probe heat pulse (DPHP) method uses two parallel rods to estimate soil volumetric heat capacity and hence volumetric water content. Most of the heat capacity of wet soil is due to its water content, and so the water content has a known relation to the heat capacity. A known pulse of heat applied to the emitter rod causes the temperature at the receiver rod to rise and then fall. The time and the size of the maximum temperature rise at the receiver are measured. Assuming that the thermal properties of the soil are spatially uniform, that the heat pulse is applied instantaneously, and that the rods have zero diameter and zero thermal capacity, the standard solution of the forward problem gives a formula for the maximum temperature rise in terms of the thermal capacity of the soil and the known parameters of the problem. Campbell *et al.* (1991) inverted this to give a solution of the inverse problem as a simple explicit formula for the soil heat capacity in terms of the maximum temperature rise and the known probe parameters.

Kluitenberg *et al.* (1993) and Bristow *et al.* (1994) introduced a calculation method that accounts for the finite probe heating duration, but requires the evaluation of the exponential integral function. Knight and Kluitenberg (2004) derived a simple power series approximation which converges well as long as the heating duration is not too big compared to the time to maximum temperature. This method is simple enough to be implemented on a small computer chip in a device. However it has been observed that the measurements are less accurate when the soil is dry, and this is likely to be due to the finite radius and finite heat capacity of the rods being neglected in the existing analysis. The semi-analytical solution of Knight *et al.* (2012) assumes that each rod is a perfect conductor, and that the presence of the receiver does not affect the temperature field near the emitter. They derived a solution of the forward problem in the Laplace transform domain and inverted it numerically, finding that the probe radius and heat capacity have a significant effect on the time and magnitude of the maximum temperature at the receiver, and hence on the accuracy of the method.

The spatial weighting function theory of Knight *et al.* (2007) for probes of zero radius provides an approximate method of calculating the apparent measured heat capacity of the soil-probe system as a weighted average of the heat capacity of the rods and the heat capacity of the surrounding soil, with the weights calculated by numerical integration and dependent on the probe radii. The weights need only be calculated once for a given probe geometry. This formula can easily be inverted to give a simple correction procedure which gives the soil thermal capacity from the measured apparent thermal capacity of the probe-soil mixture and the known probe heat capacity. As expected, a larger correction is necessary for dry soil than for wet soil, and the correction is zero when the soil and probe heat capacities happen to be the same. The procedure is simple enough to be implemented on a computer chip with limited memory and processing capacity.

The accuracy of the procedure was checked by solving the forward problem of calculating the maximum temperature rise with known soil heat capacity and probe parameters using the semi-analytical solution of Knight *et al.* (2012). An iteration procedure was then used for the inverse problem to calculate the soil heat capacity given the measured temperature rise. The agreement with the approximate value given by the spatial weighting procedure is extremely good.

It is relatively straightforward to extend the theory given here for instantaneous heating to the case of finite heating duration.

Keywords: *Soil water measurement, Dual probe heat pulse (DPHP), finite probe diameter*

Inverse of magnetic dipole field using a reversible jump Markov chain Monte Carlo

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Abstract: We consider a three-dimensional magnetic field produced by an arbitrary collection of dipoles. Assuming the magnetic vector or its gradient tensor field is measured above the earth surface, the inverse problem is to use the measurement data to find the location, strength, orientation and distribution of the dipoles underneath the surface. We propose a reversible jump Markov chain Monte Carlo (RJ-MCMC) algorithm for both the magnetic vector and its gradient tensor to deal with this trans-dimensional inverse problem where the number of unknowns is one of the unknowns. A special birth-death move strategy is designed to obtain a reasonable rate of acceptance for the RJ-MCMC sampling.

Typically, a birth-move generates an extra dipole in the field. In order to have a reasonable acceptance rate for the birth move, we try to keep the change in the likelihood function due to the extra dipole to be small. To achieve this small perturbation in likelihood function, instead of randomly adding a new dipole to the system, we replace one of the existing dipoles with two new dipoles. Ideally, the combined magnetic field produced by the two new dipoles should be very close to the magnetic field of the replaced dipole, at every measurement point. It is analytically difficult to ensure this closeness of magnetic field at every measurement point.

We can simplify the problem by ensure that the magnetic field produced by the new pair of dipoles is close to that of the old dipole at one key measurement point, for example at the centre of the measurement range. Typically the measurement points can be arranged in a horizontal rectangular lattice and that key point can be chosen to be located at the centre of the lattice. We show that for any randomly chosen dipole to be removed, we can place two dipoles with the same strength at a special location such that the magnetic field at the key point remain exactly the same as before this two-for-one replacement of the birth move. The two new dipoles are then separated by random moves similar to that of a within-model move. The death move is simply the reverse of the birth move.

Some preliminary results show the strength and challenges of the algorithm in inverting the magnetic measurement data through dipoles. Starting with an arbitrary single dipole, the algorithm automatically produces a cloud of dipoles to reproduce the observed magnetic field, and the true dipole distribution for a bulky object is better predicted than for a thin object. Multi-objects located at different depths remain a very challenging inverse problem.

Keywords: *Magnetic dipoles, Markov chain Monte Carlo, reversible jump, trans-dimensional, inverse problem*

EXTENDED ABSTRACT ONLY

Gravitational Wave Data Analysis using Chirplet-based Matched Filtering

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Abstract: An exciting prediction of the General Theory of Relativity is that the space-time metric tensor can support vibrations. Although there is strong indirect evidence for these so-called gravitational waves (GWs), direct detection has yet to occur. Such detection would provide astronomy with another "sense", so a direct GW observation is one of the highest priorities of astronomy this decade. There has been 8 years worth of data collected by the Laser Interferometer Gravitational-Wave Observatory, and a worldwide effort continues to analyse this data while the instruments are being upgraded.

GW signals are very weak by the time they reach earth, so advanced signal processing techniques are required by GW detectors. The matched filtering techniques used for GW data analysis typically assume the signal has constant frequency, and thus employ sine-Gaussian wavelets. However the GW signature of the inspiral and merger phases of binary black hole and/or neutron star coalescence in fact exhibit time varying frequencies and so are not adequately captured by these methods.

Chirplets can improve this by incorporating an additional parameter called the *chirp rate* that varies the frequency. Chirplets are defined by

$$\psi(\tau;\theta) \equiv A \exp\left(-\frac{(2\pi f)^2}{Q^2}(\tau - t)^2\right) \exp(2\pi i[f(\tau - t) + d(\tau - t)^2/2]) \tag{1}$$

where t and f are the central time and frequency, Q is the dimensionless quality factor, d is the chirp rate and $A = (8\pi f^2/Q^2)^{1/4}$ is a normalisation factor. Therefore, chirplets are described by a 4 dimensional parameter space. We can identify a chirplet in this space by the descriptor $\theta = \{t, f, Q, d\}$.

The *chirplet transform* of a signal x is computed by correlating x with a given chirplet. In the frequency domain it is defined as follows

$$T[x;\theta] = \int X(\xi)\Psi^*(\xi;\theta)d\xi \tag{2}$$

where $X(.)$ and $\Psi(.;\theta)$ are the Fourier transforms of the signal and the chirplet with descriptor θ respectively.

Chirplet-based matched filtering has been shown to result in an enhanced signal-to-noise ratio in simulated data sets for inspiral and merger GW data. This presentation will provide an in-depth discussion of this approach.

Keywords: *Chirplet, signal processing, gravitational waves*

Art Authentication from an Inverse Problems Perspective

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Abstract: In art authentication and attribution, the overall goal is to confirm whether a particular piece of art $\mathcal{P}$ is what it is claimed or thought to be. The claim $\mathcal{O}$ is likely to be an original work by a particular artist $\mathcal{A}$. Consequently, the essential *modus operandi* in art authentication is the collection of information $\mathcal{I}_{\mathcal{P}}$ about $\mathcal{P}$ to compare with the known (and, possibly, yet to be determined) information $\mathcal{I}_{\mathcal{O}}$ and $\mathcal{I}_{\mathcal{A}}$ about $\mathcal{O}$ and $\mathcal{A}$. The art $\mathcal{P}$ is often a painting, which is the current assumption, however, it can be a sculpture or pottery, in fact any artwork or antiquity, and, occasionally, a tapestry or a tablecloth.

The connection to inverse problems comes via

(a) the collection of the information $\mathcal{I}_{\mathcal{P}}$ and $\mathcal{I}_{\mathcal{O}}$, (i.e. the collection of information about the work in question, and about securely provenanced works by the artist in question),and

(b) the optimization of the comparison of $\mathcal{I}_{\mathcal{P}}$ with $\mathcal{I}_{\mathcal{O}}$ and $\mathcal{A}$ in order to have a strategy that maximizes the confirmation that $\mathcal{P}$ is a forgery when that is the situation.

In one way or another, (a) will mostly involve the recovery of information from indirect measurements, such as spectroscopic analysis or chemical analysis. It can be quite qualitative, like a visual assessment of how the paint has been applied in terms of brush stroke geometry (stylometry), or quite complex quantitatively, like the non-destructive spectroscopic determination of the composition of the white paint in the painting. From an inverse problems perspective, (b) can be viewed as an identification protocol: What items, listed in $\mathcal{I}_{\mathcal{O}}$ and $\mathcal{I}_{\mathcal{A}}$, would be the most difficult for a forger to reproduce and easy for the authentication to detect. This is a special type of inverse problem in that one does not aim to recover all the possible information hidden in $\mathcal{P}$, but just some key features which allow $\mathcal{P}$ to be quickly identified as a forgery or to increase the probability that $\mathcal{P}$ is in fact $\mathcal{O}$.

From an image analysis and inverse problem perspective, $\mathcal{P}$ is an indirect measurement (a cumulative chronological summary) of all the things that the artist (actual or forger) did in making the painting under investigation - choice of the canvas and paints, the order in which the paints were applied, the techniques and geometry of how the paints were applied. Consequently, $\mathcal{I}_{\mathcal{P}}$ is not only a compendium of specific features, such as canvass type, paint application (geometry) and composition, paint application, but also key features in the chronology of its execution, such as the order in which things were performed and the effect of the passage of time on components, in that white paints or canvases, made with more or less identical components, will have deteriorated to different states after different time intervals.

Consequently, focussed subsets of features $\mathcal{F}_{\mathcal{P}}$, $\mathcal{F}_{\mathcal{O}}$ and $\mathcal{F}_{\mathcal{A}}$ of $\mathcal{I}_{\mathcal{P}}$, $\mathcal{I}_{\mathcal{O}}$ and $\mathcal{I}_{\mathcal{A}}$, respectively, are all that are required to support the decision making. Now, for the identification of the order in which the features are utilized, specific details about the artist $\mathcal{A}$ and $\mathcal{O}$ become crucial prior information. From this perspective, the stylometry of digital images of paintings is proving to be useful and rapid in performing the initial comparison. For forgeries, the decision making is finalized the moment a falsification occurs. Consequently, in authenticiation, the goal is to order the $\mathcal{F}_{\mathcal{P}}$ so that, when anticipated, falsification occurs sooner rather than later. Because of the inverse problem nature of the recovery, some form of stabilization must be utilized. It is often performed by using key features (signatures, fingerprints).

The aim and goal of this paper is a discussion of the mentioned connection between art authentication and inverse problems concentrating on stylometry. A rapid initial test, based on the singular value decomposition of an image of a painting, is proposed for deciding whether $\mathcal{P}$ is in fact $\mathcal{O}$.

Keywords: *art authentication, inverse problems, joint inversion, boosting, feature selection, singular value decomposition*

An efficient closure based method for inverse climate modelling

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Abstract: In this study, a new method is developed for attributing changes in climate states by calculating the anomalous forcing functions responsible for these changes. The method relies on an iterative procedure to calculate improved estimates of the forcing function starting from an initial estimate. Running a sequence of climate models can be computationally demanding and therefore computational efficiency is an important ingredient in formulating a tractable inverse modelling scheme. It is therefore crucial to initialise the iterative procedure with a forcing function that is a good estimate of the correct forcing function to reduce the number of iterations required. This is achieved by formulating a statistical closure scheme. A statistical closure scheme enables one to overcome the closure problem in which statistical moments of higher order appear in the prognostic equations for the statistical moments of a given order. For example, the equation for the mean field depends on second-order moments and the second-order moment equations in turn depend on third-order moments. The closure scheme that we employ involves a linearisation of the second-order moment terms, which physically represent the feedback of transient eddies on the mean circulation, in terms of the mean fields. The parameters required in this closure scheme are calculated by employing perturbation experiments. We demonstrate that the closure scheme leads to simulated climate states that are in close agreement to idealised and observed climate states with pattern correlations generally greater than 0.8. These closure based estimates may then be further improved by employing the iterative method.

Keywords: *Inverse modelling, climate change, attribution, closure, eddy parameterisation*

High-resolution bushfire hazard mapping of the current and future climate to inform planning for the Rockhampton region

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Abstract: The dry-tropics of central Queensland has an annual bushfire threat season that generally extends from September to November. This study aimed to identify the bushfire hazard at the local scale in the Rockhampton region under current and future-climate conditions. It draws on General Circulation Model (GCM) simulations, and builds on those outputs by applying a novel hazard modelling technique to develop an understanding of bushfire hazard at the local level in the Rockhampton region. Fire weather hazard is quantified using either the Forest Fire Danger Index (FFDI) or the Grassland Fire Danger Index (GFDI) (Luke and McArthur, 1978). In these, weather observations (temperature, relative humidity and wind speed) are combined with an estimate of the fuel state to predict likely fire behavior if an ignition occurs.

For current climate, the *average recurrence interval* (ARI) of FFDI at Rockhampton Airport was calculated from observations by fitting the Generalised Extreme Value (GEV) distribution known as the Generalised Pareto Distribution (GPD). A high resolution numerical weather model (dynamic downscaling) was utilised to provide spatial texture of weather over the Rockhampton region for days where bushfire hazard (as measured at the Rockhampton Airport meteorological station) was known to be severe to extreme. Each of these FFDI grids then was normalised to the value of the FFDI at the grid point corresponding to Rockhampton Airport, and an ensemble average was produced which related to the 50 and 100 year ARI for the FFDI for the Rockhampton region (current climate).

For future climate, we considered three downscaled GCM's forced by the A2 greenhouse gas (GHG) emission scenario. The spatial pattern of the 50 and 100 year ARI FFDI for the Rockhampton region (future climate) was determined from the ensemble average of the 2050 and 2090 period GCM outputs. In general, a small spatial increase in the FFDI was reflected in the ensemble model average for 2050 through to the 2090 climate. This was reflected throughout the Rockhampton region in both magnitude and extent through 2050 to 2090. Cluster areas of higher (future climate) bushfire hazard were mapped for local council planning consideration.

To determine bushfire hazard, the FFDI alone does not provide the complete picture of fire hazard. FFDI needs to be combined initially with a weighting based on the vegetation type because FFDI is based solely on forested vegetation. This weighting was derived from a vegetation map of the region. The map was created using a supervised classification of LANDSAT TM imagery and merging of the classified layers into a small number of discrete groups. Combining FFDI and vegetation, and applying the classifications developed for the new fire danger rating system by the National Bushfire Warnings Taskforce, (established following the Victorian bushfires of February 2009), a *bushfire hazard map* was produced. This bushfire hazard map also required details of where the bushfire hazard was considered to be above the levels allowable for future development. To address this, two factors were added, "setback from closed forest" and "slope", to introduce buffer regions where development should not occur.

This study did not carry out a formal analysis of the assets at risk from bushfire, but such an analysis could be undertaken using the digital data produced. The Rockhampton region was already characterised by high hazard levels for a range of hazards. The region has a history of cyclonic winds and storm surge events, as well as bushfires and frequent flooding. This study formed part of a Rockhampton Regional Council project that aimed to evaluate the ability of its existing urban planning principles and practices to accommodate climate change and the uncertainty of climate change impacts (Moore *et al*. 2013). The results of this study provide an assessment of local bushfire hazard from extreme events for a particular emissions scenario. Land use planning should consider how the projected future hazard level would impact on proposed development.

Keywords: *hazard mapping, bushfire hazard, fire danger, FFDI, recurrence interval*

A methodology for evaluating the impact of visualization on decision-making under uncertainty for PHOENIX Rapidfire

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Abstract: PHOENIX Rapidfire is fire spread modeling software that uses a variety of different inputs to predict bushfire spread. As with all models, there is uncertainty associated with the output. Uncertainty can be caused by several factors including weather conditions, fuel type and fuel loads. In this study, uncertainty related to the point of ignition of the fire is considered. Therefore, evaluation of different visualizations is required to determine how best to display and communicate this uncertainty. This is of particular importance in Australia, due to the need for the public to make their own informed decision of whether to vacate their home in a bushfire as there are no compulsory evacuation orders issued.

The visualization techniques chosen for this study include two well-known representations used in the fire services sector today. The first of these is the visualization used to represent the output from the PHOENIX model, which is represented as a hard line showing the highest burn likelihood, followed by a dashed line for the lowest burn likelihood. The second is the representation used by FS PRO fire spread prediction model, which consists of bands of different colours to represent burn likelihood, with no clear value message. Additionally, we selected three more visualization techniques that are commonly used for communicating uncertainty, and are reported to be suited to representing quantitative categorical information. These techniques – transparency, texture and color value, to our knowledge have not been previously evaluated for decision-making in bushfire situations.

This research explores and evaluates the practical implications of these techniques for communicating uncertainty and provides suitability measures and guidelines for the practical use of these visualization techniques for decision-making in bushfire situations. Human subject experiments are the main method used for evaluation. The results of this evaluation will be incorporated into PHOENIX Rapidfire to better enhance the capability and usability of the model's output.

Keywords: *Visualization, uncertainty, decision-making, bushfires*

Will environmental revegetation increase the threat wildfire poses to assets?

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Abstract: Active and passive revegetation is dramatically altering vegetation characteristics across agricultural landscapes globally. There is concern within communities that increased fuel loads associated with revegetation will increase the threat wildfire poses to assets (i.e. life and property). However, the validity and generality of these concerns has not been examined and therefore requires scrutiny. Inherent difficulties associated with the experimental manipulation of fire and the detailed documentation of fire behavior during wildfire events necessitate the need for simulation modeling to address this complex environmental issue. The PHOENIX fire characterisation model was utilised to investigate how the presence and size of revegetation plantings and their proximity to assets (i.e. buildings) influence 'wildfire risk' within a cleared pasture landscape. Elements of 'wildfire risk' examined included (i) the likelihood that fire would reach an asset, (ii) the intensity of fires at an asset and (iii) ember density at an asset. One hundred plantings 990 m long were established within an agricultural matrix and six 'assets' were located within and at set distances from each planting relative to the fire line ignition (in front of the planting, within the planting and 90 m, 270 m, 540 m and 990 m behind the planting). The width of plantings was varied across simulations (no planting, 90 m, 270 m, 540 m and 990 m). Fires were simulated under a range of fire weather (25 weather streams) and pasture biomass (2 tha^{-1}, 4.5 tha^{-1} and 7 tha^{-1}) conditions. This resulted in 375 simulation runs with 600 assets being sampled in each simulation (i.e. 225 000 data points in total). The inclusion of plantings did not increase the likelihood of fire reaching an asset, with large plantings (i.e. 540 m and 990 m wide) actually reducing the likelihood under certain conditions (i.e. low pasture fuel loads, moderate weather conditions). The intensity of fires within the pasture matrix was dependent upon pasture biomass and weather conditions, not the presence or size of plantings. The addition of plantings did increase the risk of embers reaching an asset. However, the density of embers was generally low (i.e. <10 embers/ha) at sampling locations that were not directly adjacent to the planting (i.e. $\geq$ 270 m). In general, weather and pasture biomass had a greater influence on 'wildfire risk' than plantings. These results suggest plantings are likely to have little impact on the threat wildfire poses to built assets and that wildfire risk will be more strongly determined by fire weather and pasture management. The approach used in our study provides a useful method to quantitatively assess the relative effect environmental plantings will have on the risk fire poses to built assets under a range of environmental conditions.

Keywords: *PHOENIX rapidfire, fire risk, revegetation*

Modelling the impact of climate change on lightning ignition of bushfires

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Abstract: Fires ignited by lightning ('lightning-fires') typically burn a larger area of land than fires ignited by other sources, due to lightning often occurring in large temporal and spatial clusters in remote regions that are sparsely populated and difficult for response personnel to access. Lightning-fires can also have catastrophic impacts on densely populated regions, such as was the case for the January 2003 Canberra fires. However, few studies have attempted to model the occurrence of lightning-fires, particularly in Australia. Additionally, very little is known about the influence of climate change on lightning-fires. These knowledge gaps are currently being examined, with results presented here, by a project within the Australian Climate Change Science Program.

High-based thunderstorms with dry air at lower levels were previously found to provide a good indication of a high risk of lightning-fire occurrence in Victoria. Additionally, a variety of other potential factors were found to influence the temporal and spatial variability of the risk of lightning-fire occurrence, including the influence of atmospheric conditions (at the surface and above), fuel characteristics (moisture content, size/depth and type) and dry-lightning (lightning that occurs without significant rainfall).

Building on this previous research, subsequent investigations have recently been undertaken to model the risk of lightning-fire occurrence, for potential application to coarse resolution data (e.g. global climate models). Initial results from these investigations consider seasonal differences in Pearson correlation coefficients between monthly anomalies of lightning flash densities and the NINO3.4 index (as a measure of the El Niño/Southern Oscillation: ENSO). Lightning flash data were obtained from two NASA satellite sensors: the Lightning Imaging Sensor (LIS) and the Optical Transient Detector (OTD) based on a monthly gridded time series product (named "LISOTD_LRMTS") during the time period from 1995 to 2011. The spatial resolution of the lightning data is 2.5 degrees in both latitude and longitude, although prior to being released for public use the data are smoothed with a 7.5°×7.5° and 111-day boxcar moving average. The geographic study region used here covers all longitudes throughout Australia, and ranges in latitude from 38.75°S to 38.75°N due to the field of view of the LIS sensor. The NINO3.4 index data were obtained from the Climate Prediction Centre (CPC) of the National Oceanic and Atmospheric Administration (NOAA).

Significant relationships occur between lightning activity and the NINO3.4 index in each of the four seasons for different regions throughout Australia, with a significant correlation at the 95% level (corresponding to $|r| \geq 0.43$). Previous studies have examined the relationship between ENSO and lightning activity in various different regions throughout the world, although this is the first time that this relationship has been examined for four individual seasons throughout the year, including with a specific focus on the Australian region. We have shown here that large-scale phenomena, such as ENSO, can have a significant influence on the seasonal lightning climate of Australia. Information such as this (i.e. knowledge about the factors that influence the chance of lightning occurrence) could be combined with information relating to the chance of fire given the occurrence of lightning, to undertake climatological investigations of lightning-fire occurrence. An improved ability to model lightning-fires could be expected to produce benefits such as a reduction in the response time to these fires and thus a reduction in the damage that they cause. It is also expected to lead to an improved ability to model carbon budgets, given that lightning-fires are responsible for a large proportion of annual carbon dioxide emissions.

Keywords: *Fire, lightning, climate, extreme weather*

A comparison of the fire weather characteristics of the Melbourne dust storm (1983) and Black Saturday (2009): a high-resolution ACCESS case study

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Abstract: We present the results of high-resolution simulations of the fire weather over Melbourne during its notorious dust storm on 8 February 1983. The simulations were performed using the Australian Community Climate and Earth-System Simulator (ACCESS), and involved a sequence of nested model runs starting with a global model run initialised with an ERA-Interim reanalysis initial condition. The ACCESS model is used at the Bureau of Meteorology for operational numerical weather prediction, but is used here in research mode at resolutions much finer than those currently used operationally.

The day of the dust storm saw the passage of a significant cool change across Victoria, with many similarities in the simulations to that of Black Saturday (7 February 2009), against which we compare it. Wind changes such as these two can have a significant (and dangerous) impact on the behaviour of bushfires in southeast Australia, and their prediction forms an important component of fire weather prediction in this part of the country. While the wind change on 8 February 1983 was accompanied by some fire activity, that activity was much less than the major fire activity which accompanied the significant wind change eight days later on Ash Wednesday (16 February 1983).

Why the dust storm wind change was not associated with severe fires, while those on Ash Wednesday and Black Saturday were, is a challenging question. Catastrophic fires are quite rare, whereas significant fire weather events that could potentially lead to catastrophic fires (if the non-meteorological prerequisites were to fall into place) are much more common and their study can lead to further understanding of the fire events.

Keywords: *Fire weather, numerical weather prediction, Melbourne's dust storm, Ash Wednesday, Black Saturday.*

Modelling the fire weather of the Dunalley, Tasmania fire of January 2013: an ACCESS case study

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Abstract: We present the results of high-resolution (0.012°, i.e. ≈ 1.3 km, grid-spacing) and very-high-resolution (0.004°, i.e. ≈ 440 m, grid-spacing) simulations of the fire weather over southeast Tasmania around the time of the Dunalley fire (which started at about 0300 UTC on 3 January 2013 near the small town of Forcett). The simulations were performed using the Australian Community Climate and Earth-System Simulator (ACCESS), and involve a sequence of nested model runs starting from a global model run initialised with an initial condition prepared by the Bureau of Meteorology's National Meteorological and Oceanographic Centre. They cover the 50-hour period from 0300 UTC on 3 January to 0500 UTC on 5 January 2013. Our analysis will focus on how well the simulations capture the meteorological factors that promote extreme fire behaviour. The ACCESS model is used at the Bureau for operational numerical weather prediction, but is used here in research mode at much finer resolutions than current (0.036°) operational ones.

On 4 January 2013, a familiar set of summer meteorological ingredients: (i) an approaching cold front west of Tasmania, and (ii) an anticyclone in the Tasman Sea between New South Wales and New Zealand, brought strong hot northerly to northwesterly winds over southeast Australia and Tasmania in particular. These conditions occurred during a significant national heatwave that contributed to January 2013 being the hottest month on record for Australia.

The 4th of January saw numerous high temperature records set in southern Tasmania, most notably its capital city Hobart, whose maximum of 41.8 °C was the highest in 120 years of records there, the highest on record anywhere in southern Tasmania, and the second-highest for the State as a whole. On that day, thousands of people, including summer holiday makers, were stranded on the Tasman Peninsula (TP) as bushfires cut off road access, with many evacuated by water back to Hobart. The fires destroyed many properties in Tasmania, news media reporting at least one hundred, with Dunalley particularly badly hit.

Two weather stations in southeast Tasmania (Hobart and Campania) measured "catastrophic" Forest Fire Danger Ratings (FFDRs) at routine observation times on the hour. Over periods ranging from one minute to one hour, five weather stations registered "catastrophic" FFDRs, these being Hobart, Campania, Hobart Airport, Bushy Park and Dunalley (all near to, but not on, the TP). At Dunalley, as fire swept through the township, radiant heat from the fire corrupted the air temperature readings at the Bureau's automatic weather station.

The 0.004° simulations show notional instantaneous Forest Fire Danger Index (FFDI; a Drought Factor of 10 is assumed) values peaking in the FFDR "catastrophic" range (> 100) across the TP, comparable to the observed "catastrophic" values at the non-TP sites mentioned above, but the 0.012° simulations show less intense values. Afternoon maximum temperatures and wind directions are generally well modelled, although some of the fine-scale local wind changes were not captured in the simulations. The passage of the primary wind change (from northerly to southerly) in the simulations shows a complicated interaction with the topography and coastline of southeast Tasmania. Wind changes such as this one can have a significant (and dangerous) impact on the behaviour of bushfires in southeast Australia, and their prediction forms an important component of fire weather prediction.

This work arose through a project funded by the Bushfire Cooperative Research Centre, to produce very-high-resolution meteorological simulations for significant recent fire events. The intent is for a better understanding of the meteorology of those events and the use of the simulation results in fire spread and fire impact modelling.

Keywords: *High-resolution numerical weather prediction, fire weather, bush fires*

Australian Bushfire Fuel Classification System

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Abstract: Quantifying fire prone vegetation is a challenge for land managers who need explicit current, trending and future fuel data to manage fire hazard, predict fire behaviour, understand suppression difficulty, evaluate fire impact on human and ecosystem values and measure their carbon stocks. The Australasian Fire and Emergency Service Authorities Council (AFAC) and the Forest Fire Management Group (FFMG) recognised the need for a national fuel classification to ensure a nationally appropriate method of characterising and quantifying fuels.

As a key feature the Australian Bushfire Fuel Classification should enable the categorisation and organisation of fuel complexes in order to capture spatial diversity as well as dynamic and structure complexity in a way that accommodates existing models for fire behaviour and assists development of the next-generation of fire management Decision Support Systems.

This paper presents the results of a collaborative interagency effort to develop a nationally consistent and locally relevant bushfire fuel classification for fire management in Australia. The paper introduces the concept and framework for the Australian Bushfire Fuel Classification (ABFC), provides a general overview of the proposed ABFC and highlights the interdependency on multiple data sources and applications and describes the case study process used to test the framework operationally across field fuel plots and the resultant GIS layers. Finally, it discusses the need for a cohesive interagency effort to initiate and implement the ABFC and a business model to find a custodian to maintain and update the system.

The main objectives of the fuel classification are:

(i) to synthesise and catalogue fuel attributes required by fire behaviour models and other land management tools (e.g. smoke production, carbon release) into a finite set of classes or categories that ideally represent all possible fuel beds or fuel types in a region and their subsequent fire behaviour and effects

(ii) to catalogue fuel attributes and parameters describing the dynamics and physical structure of each fuel type

(iii) to maintain a fuel library (containing concepts, definitions, and references) and documentation of procedures and guidelines for assessment and inventory of fuels.

The ABFC consists of a design framework and a set of standards for fuel classification. The framework provides a structure to allow fuel to be described by its component type and structural form based on vegetation categorisation and relates these to the fuel parameters and attributes. The fuel attributes are those physical and chemical parameters that affect ignition, heat release, rate of combustion and spotting potential. The completed standards are a glossary of fuel terms and a guideline for measuring fuel parameters. It is proposed to include a standard on dynamic fuel models.

The system is supported by AFAC member agencies and should form the basis of their fuel classification work into the future. The approach is designed to be adaptive and learn from its application. It can accommodate the changing needs of users. It is hoped that it will be widely supported in the scientific community as providing a stable base for describing fuels, avoiding duplicated classifications and building a consolidated reference library of comparable fuel data.

The system was funded by the Attorney-General's Department through the National Emergency Management Program (NEMP 1112-00043, Australian Bushfire Fuel Classification System). It will lead to greater interoperability between state-based fire agencies if fuel classifications are common or at least comparable between incidents and planning across state boundaries and as agency staff rotates between incidents. Work has now commenced to develop a business case for the ongoing maintenance and custodianship of the system.

Keywords: *Bushfire, fuel classification, fire management*

Economic analysis of prescribed burning for wildfire management in Western Australia

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Abstract: Bushfires can cause significant damage to ecosystems, life and property, and bushfire events that do not involve impacts to people and property are becoming rare. Protecting human and environmental assets is becoming more difficult as the wildland–urban interface expands in Australia. Climate change scenarios generally indicate a likely increase in the number of extreme weather days which may significantly influence bushfire hazard distributions in the short and long term. In light of the increasing wildfire threat, fire agencies have often responded with greater suppression capacity, involving increasing costs. However, this has not solved the problem of major impacts during catastrophic wildfires. In this context, it becomes increasingly important to implement sustainable fire management strategies and gain improved understanding of the effects of alternative fire management programs on reducing bushfire risk.

From an economic perspective, the main objective of fire management is to maximise social welfare by optimally allocating the resources used before, during and after fire events to achieve the most efficient outcome in terms of costs and damages avoided. In this sense, economics can provide improved understanding and comprehensive appraisals of wildfire costs and benefits in order to devise wildfire mitigation and management programs that optimally allocate resources and express informed, evidence-based judgements about trade-offs between available options. Insights from economic analysis can help fire agencies evaluate the implications of different options for uses of limited human and financial resources and to inform decisions about their allocation to different fire management activities. However, the use of economics in the bushfire literature is still relatively limited and empirical economic analyses of bushfire management remain scarce. This study provides a comprehensive economic evaluation of alternative prescribed burning programs in the south-west of Western Australia to determine the optimal prescribed burning strategy for the region.

The south-west of Western Australia presents an interesting case where we simultaneously find a wildland–urban interface scenario, medium and tall Eucalyptus forests, and unique biodiversity. In this region, highly flammable vegetation and human assets are intermingled. Eucalyptus forests cover a large part of the south-west region and some eucalyptus tree species are unique to the area. Based on its natural richness in amphibian species and endemic plants, the south-west is recognised as one of the world's biodiversity hot-spots. In this context, it is important to gain improved understanding of trade-offs between conflicting objectives, such as asset protection and biodiversity conservation.

We applied the Cost plus Net Value Change (C+NVC) approach to the prescribed burning program implemented in the South West Forest Region of Western Australia. We used the AUSTRALIS Bushfire Simulator to simulate fire events under varying climatic conditions and different prescribed burning strategies to identify the optimal prescribed burning policy. The C+NVC approach is the commonly accepted model for evaluating bushfire management programs. It is a monetary–based framework that identifies the level of pre-suppression expenditure that minimises the total sum of pre-suppression costs (e.g. prescribed burning), suppression costs and net fire damage, and is closely related to a benefit–cost analysis. In this model, pre-suppression is the independent variable that determines suppression costs and damage. The underlying assumption in this formulation is that initial investment in pre–suppression results in gains in terms of reduced damage and suppression costs, but that at some point those gains diminish.

Keywords: Bushfire management, prescribed burning, economic analysis, cost plus net value change

Future fire danger and ground moisture climatology for Tasmania using a dynamically downscaled regional climate model

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Abstract: We generated daily values of Soil Dryness Index (SDI) and McArthur Forest Fire Danger Index (FFDI) at approximately 10 km resolution over Tasmania from a suite of six dynamically downscaled climate models from 1961 to 2100 using the A2 SRES emissions scenario. The mean model FFDI validated well against available observations for 2003-2012, when the density of Automatic Weather Stations in Tasmania was sufficient to provide representative cover, with 99th percentile fire danger having the same distribution and largely similar values to those observed for the same time period.

SDI values were derived from model temperature and rainfall data subject to quantile-based bias-adjustment in 1% bands, calculated seasonally against AWAP for each cell in each downscaled model for the period 1961-2007 (inclusive), and applied to corresponding cells within each 140-year simulation. Extensive validation ensured that mean spatial and temporal correlations were improved and distributional features were preserved. SDI is primarily an input to the fire danger calculations, underpinning the fuel moisture component of FFDI. However, SDI is also of interest to land managers in its own right, allowing assessment of the likelihood of fire ignition being sustained. Hence, we derived trends in decadal average SDI for weather forecast districts in western, central and eastern Tasmania. For all models, and in each district studied, SDI increased through the current century.

There was a broad increase of FFDI during the model period evident across most of Tasmania, but with substantial regional variation – the increase was smaller in the west of the state compared to the southeast and midlands. The increase accelerated in the latter part of the century. There was also noticeable seasonal variation, with little change occurring in autumn, but a steady increase in springtime 99th percentile FFDI, particularly in the east. There was evidence that annually accumulated FFDI behaved in the same fashion. These results are consistent with observations, where, for example Fox-Hughes (2008) notes a marked increase in recent decades of springtime fire weather extremes in the east and southeast of Tasmania.

Regional mean sea level pressure patterns corresponding to elevated FFDI in the model were shown to resemble observed patterns associated with days of historically dangerous fire weather. These synoptic weather patterns increased in frequency during the simulated twenty-first century, in 21 of the 24 scenarios investigated (based on changes in event frequency at four locations in each of the six individual model runs).

The broad correspondence of the model output with available observations and the regional detail that can be seen indicate that these dynamically downscaled model data contain projections of future ground moisture and fire danger that are useful for landscape managers and the community.

Keywords: *fire danger, fire weather. regional climate modelling, soil dryness index*

FireDST: *F*ire *I*mpact and *R*isk *E*valuation *D*ecision *S*upport *T*ool – model description

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Abstract: Australia needs to develop and use sophisticated fire modeling techniques as an aid in the prevention and mitigation of bushfires (COAG 2002). This was reinforced by the recommendations from the Victorian Bushfire Royal Commission (VBRC 2010) following the disastrous "Black Saturday" fires of 2009. In 2011, the Australian Bushfire Cooperative Research Centre initiated the FireDST (Fire Impact and Risk Decision Support Tool) research project with a focus on all aspects of modeling extreme fires in Australia including the development of a "proof-of-concept" computer system that could predict the likely probabilistic spread of a bushfire that has already ignited.

The FireDST "proof-of-concept" system links various databases and models, including the Australian Bureau of Meteorology's new "high resolution" ACCESS (Australian Community Climate and Earth-System Simulator) numerical weather prediction system, the PHOENIX RapidFire fire spread model, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) building vulnerability assessment model, infrastructure and demographic databases provided by Geoscience Australia and CSIRO's smoke dispersion model is the last stage of the system, and it provides spatial information regarding smoke concentration and likely human impacts. The information is assembled into an integrated simulation framework through a geographical information system (GIS) interface. The Australian Bureau of Statistics (ABS) Census-derived social and economic information as well as extensive quantity surveying of asset values are also included

FireDST is designed to produce probabilistic results that are based on an understanding of the issues that may occur. For example simulating multiple individual fires that have different ignition points and start times, vegetation and fuel characteristics, and variations in wind speed and direction. All the individual simulations are amalgamated into a probabilistic view of the fire spread based on the estimated uncertainties.

This paper provides an overview of the FireDST simulation "proof-of-concept" tool and walks through a sample probabilistic simulation constructed using the tool. The "proof-of-concept" system has demonstrated the successful generation of probabilistic fire spread as well as the impact associated with the probabilistic fire spread. Graphs and tables provide the exposure results (e.g. those houses and people in the 76-100% probability area).

FireDST is designed to be used to assist in the management of bushfires, land use management (e.g. predicting extent and effectiveness of controlled burns), land planning (such as siting of infrastructure to be less exposed to bushfires) and in education. This paper describes the model in the context of its use in bushfire management by providing an example simulation that emulates the disastrous Kilmore Fire in Victoria on 7 February 2009.

Keywords: *bushfire hazard and impact, impact simulation, integrated modeling/simulation*

Parameter sensitivity evaluation in bushfire spread modelling

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Abstract: Bushfires have shaped the historical ecology and landscape of Australia. However, increasing urbanization is leading to the potential exposure of greater numbers of people to the devastating consequences of bushfires, especially at urban-rural boundaries. Understanding the behaviour of bushfires is therefore becoming increasingly important for developing fire containment strategies and predicting the risks to humans and infrastructure from these events. Fire behaviour is usually characterised using a set of measureable parameters including the rate of spread (ROS) which defines the behaviour of the fire front over time. Due to the importance of predicting fire front behaviour, research and development of empirical ROS models have a long and extensive history. Such models usually give a one-dimensional spread rate from a set of input parameters incorporating factors such as terrain, slope, wind, moisture and a range of fuel parameters. Examples of such models include Rothermel, McArthur and Vesta rate of spread models. The inputs to these models are often given as single values representing underlying data distributions. The sensitivity to this simplification, and the potential implications for the prediction of the rate of spread, have not been examined in detail and are the focus of this study.

One-dimensional spread relations can be used as the basis of two-dimensional computational spread models. Such models attempt to simulate the spread of fire over landscape, dynamically including the spatially varying factors required for the one-dimensional relations. These simulation models can be divided into two approaches. In front-tracking approaches the fire front is calculated using overlapping stencils based on experimentally determined fire spread shapes. Cellular approaches involve dynamically calculating the fire front from spatially discretised quantities on an underlying computational mesh. In this study a cellular model where the fire front is represented as the isoline of a scalar field is implemented and investigated. This is known as a level set method, and is currently used in newer fire spread models such as SFIRE. The level set method provides a natural way for moving a front with a variable speed, as well as a straightforward ability for fronts to merge and collide. This removes the need for complex inter-front collision algorithms used in front tracking methods.

Such computational models based on empirical rate of-spread relations can quickly give predictions of fire spread over large domains. However, the underlying assumptions made for these models are often simplifications of complex underlying processes and data. In particular, input data is often temporally or spatially averaged. Examples include fuel parameters or wind speeds being a single averaged value within a particular computational grid cell. The sensitivity of computational fire spread models to variations in these parameters is not fully understood. The current research focuses on developing such an understanding for the level set method, as well as investigating the potential consequences of using such simplified assumptions. First, input parameters are selected and allowed to vary according to pre-determined statistical distributions which can change through time and space. Numerous fire spread runs with different input criteria are generated. Second, whether, and how best to evaluate and visualize the sensitivity of the fire spread model to these variations is explored.

Incorporating a probabilistic approach to generating and analysing various bushfire scenarios provides a crucial understanding of the sensitivity of input parameters to the fire spread prediction. Visualisations allow us to understand the parameter sensitivity of such models in a spatial context, as well as express uncertainties which improve communication of risk in fire spread contexts. Our findings can be used to guide future model development for more sophisticated computational ROS approaches.

Keywords: *Bushfires, Rate of spread model, Level set, Sensitivity analysis*

Meteorological Aspects of the Margaret River Fires of November 2011

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Abstract: Early in the morning of Wednesday 23 November 2011, a fuel-reduction burn near Margaret River in southwest Western Australia increased dramatically in activity. The fire escaped control lines and burnt southwards along the coastal fringe, subsequently destroying 32 homes, including the historic Wallcliffe House, and damaging others. Satellite imagery showed a smoke plume of vastly greater extent than other fires in the area.

Here, we present a preliminary analysis of the meteorology of the event, based on very high resolution (400 m) simulations with the Bureau of Meteorology's ACCESS numerical weather prediction (NWP) system and available observations. We find that several mesoscale features likely contributed to the fire becoming or remaining active overnight. The first of these was a region of marked near-surface drying over and around the fire ground, contrary to the normal diurnal cycle and due to the advection of dry air from inland regions to the northeast of the fire. The second was the development of strong mountain-wave activity and downslope winds over the fire during the Tuesday night and extending into Wednesday morning, caused by a combination of a strengthening pressure gradient as a high pressure system passed to the south of the region, nocturnal cooling, and the local topography. The third was the development of a pronounced low-level jet, which provided a source of strong momentum for the mountain waves to bring to the surface.

During the day, while the fire was heading rapidly southwards under the influence of strong hot northerlies, the observed increase in activity around midday may have been due to a lengthy, coherent wake shed from hills to the north of the fire.

The essential dynamics of mountain waves are quite well known, although their occurrence on topography as low as here presents some forecasting difficulties, since the common assumption of inviscid flow cannot be made when the "mountain" is contained entirely within the boundary layer. Nevertheless, strong nocturnal downslope winds form a recognised part of the climate of both Perth and Adelaide, and likely occur in other regions also. Their influence on fire behaviour in Australia does not seem to have been widely documented before, although Sharples (2009) identifies one case. We expect that similar winds will occur again and recommend that managers of lee-slope fires exercise appropriate caution in the future, especially overnight and in the morning.

Keywords: *Fire weather, downslope winds, low-level jet, ACCESS, high-resolution NWP*

Data Assimilation – or, How to Make Fire Modelling Even More Useful

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Abstract: Simulations inevitably differ from observations. Therefore, if simulations are to be used for real-time prediction in practical applications, there needs to be an objective and automatic way to adjust the model state back towards the observations.

This problem, of blending a model prediction with observations, arises in many fields. In meteorology, it is at the heart of modern weather forecasting and is known as Data Assimilation (DA). In weather forecasting, the benefits of DA extend well beyond operational forecasting, and include the reanalysis of past events, filling in the gaps between observations, the preparation of forecasts with error bars, making optimal use of expensive observations, and even the design of observing systems.

In principle, similar benefits could accrue to bushfire modelling. Consider the following scenarios:

1. A fire agency is managing a large bushfire with the help of a fire modelling system. Reports indicate that the fire is spreading faster than the model predicts. The agency would like to update the simulation to take account of this new information, but redefining the fire perimeter in the model by hand is slow, subjective and requires a significant amount of highly skilled labour. As the fire day worsens, it becomes impossible for the human to keep up. Automatic updates would free the expert to interpret, communicate and make decisions based on the data – rather than trying to keep up with analysis.

2. An observation indicates that, at one location, the modelled fire-front is in the wrong spot. Clearly it is likely to have a similar error at other nearby locations. But how much of the fire-front should be adjusted based on this one observation, and by how much? How should the model data on, say, fuel consumption, be adjusted to reflect this change?

3. A fire agency requires a set of daily fire isochrones for research purposes, covering every fire in the state for the last twenty years. All they have are ignition location and time, and final perimeter and final date, together with some scattered data on when and where fire crews had engaged the fire. How can they estimate reasonable daily burn data for the past two decades without resorting to an expensive, subjective and slow manual procedure?

Bushfire assimilation will present some particular challenges that are absent in other DA problems. First and foremost among these is that, for practical reasons, DA methods usually assume that the errors in observations and the model state are Gaussian. This is a poor assumption when a given location is either burning or not. DA systems perform best when they are making small adjustments to the model state – moving the fire front will change the burning/non-burning status of some locations, which is not a small adjustment.

The paper surveys some existing DA methods, and assesses their suitability for use with bushfire models, with the aim of stimulating discussion and research in this important area. We will also attempt to identify the barriers that will have to be overcome to achieve an operational bushfire assimilation and prediction system.

Keywords: *Bushfire models, data assimilation*

Coupled atmosphere-fire simulations of the 2003 Canberra bushfires using WRF-Sfire

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Abstract: Numerical simulations of bushfires have the potential to increase our knowledge and understanding of bushfire behaviour and to provide predictive information in operational situations. All such simulations require simplified mathematical models if they are to be run in a reasonable amount of time, but these models are becoming increasingly sophisticated as computer technology continues to advance. It is now possible to run simulations of large-scale events with dynamic coupling between the fire and the atmosphere in real time, as recently demonstrated using WRF-Sfire (Kochanski et al., Forest Ecology & Management, 294, 2013).

Here, we present results from WRF-Sfire simulations of the Canberra fires on January 18, 2003. This is one of several simulations we have run that are aimed at better understanding the capabilities and limitations of WRF-Sfire. Previous idealised simulations of this event used fixed heat and moisture fluxes that were estimated from observations of the actual event, measured vertical profiles of temperature and velocity as boundary conditions, and flat topography (Cunningham & Reeder, Geophysical Research Letters, 36, 2009). Here, the existing WRF-Sfire fire-behaviour model is used to dynamically predict the evolution of the fire front and the associated fluxes, subject to atmospheric influence.

The simulations are run on four nested domains. The outer domain is 900 km x 900 km in extent with a horizontal resolution of 9 km, while the inner domain is 65 km x 65 km in extent with a horizontal resolution of 333 m. A stretched vertical grid is used, with a resolution of about 25 m near the ground and vertical extent of 20 km. Atmospheric boundary and initial conditions are obtained from archived global simulations and high-resolution (90 m) topography is used. The fire model is run on a grid with a horizontal resolution of 33 m. The fire is initialised from published fire maps, and is assumed to be homogeneous, with a nominal loading of 3 kg/m2 and a moisture content of 4%. Additional simulations were run to explore the effects of fire initialisation (geometry and timing), fuel load, rate of fuel consumption and moisture release.

These simulations do not appear to reproduce some of the extreme fire-weather interactions that occurred. Although there is some vertical development simulated in the region of the observed pyrocumulonimbus (seen from our analysis of the vertical velocity and relative humidity at a height of approximately 5,800 m.), it does not appear to be on the same scale as the massive pyrocumulonimbus that was actually observed.

Keywords: *Fire weather, bushfire modeling, coupled bushfire simulation*

A process model for forecasting conditions conducive to blow-up fire events

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Abstract: Extreme fires are responsible for devastating losses in recent years in Victoria, New South Wales and the ACT. Detailed case studies have revealed that an extreme fire will include one or more blow-up fire events. The importance of this is that, unlike extreme fires, blow-up fire events are relatively predictable. Using the outcomes from a number of recent studies, we believe that it is becoming feasible to forecast conditions conducive to blow-up fire events.

Here we present a process model for the purposes of forecasting conditions conducive to blow-up fire events.

Implementing the model requires collaboration between the fire agency duty officer and the duty forecaster. They require information about: the fire and from the fire ground; forecasts and observations; and specific data on terrain. This collaboration needs to be more formal than current arrangements, as no one participant can be expected to have sufficient information on-hand to produce a forecast of a blow-up fire event.

This information is used to answer a series of questions, arranged as steps in a flowchart, which will either loop-back or lead to the inference of conditions conducive to blow-up fire conditions. The steps in the flowchart have differing timeframes associated with them, firstly for impact lead time ahead of blow-up event formation, and secondly for predictability. Predictability of weather events includes both forecasting their occurrence and tracking their approach or development. These elements used by the model need to occur together, which may happen at different times in different places, due to the differing dynamics of the weather and the fire.

A key element of the model is separating elements of existing fire weather indices into components. Two key examples are discussed. The Fire Danger Index is equivalent to wind speed divided by fuel moisture content (FMC). FMC in turn reflects the difference between temperature and relative humidity. The Continuous Haines Index is based on a lapse rate term and a dryness term. While each index is useful, we demonstrate that working with their components provides greater functionality.

In addition, the movement of a fire into fire channelling prone terrain, may reflect suppression operations, which could prevent a blow-up event forming or, in a worst-case scenario, cause one.

The utility of the model is demonstrated in the context of a number of recent notable fires.

Keywords: *Fire weather forecasting, extreme fires, blow-up fire event*

Assessing the Exposure Risk of Regional Populations to Smoke from Fires

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Abstract: The potential health impacts from smoke are well known. Protracted exposure of rural and urban populations, particularly the more susceptible groups including the elderly, people with impaired cardiovascular function and allergies, extends the risk from bushfires to the entire population and, in some cases, due to the number of people exposed, may constitute the greatest risk to health. The cost of these impacts can be substantial. Consequently smoke management is now a major issue for fire agencies. The exposure risks vary widely with the class and location of the fire events, and range from extensive fumigation of SE Australian populations from fires that persist for weeks to localised impacts from small fires. The fire decision tools project of the Bushfire Cooperative Research Centre has been developing techniques for assessing the risks and impacts through a series of case studies. The key issue to emerge is not the total emission of smoke, but the extent to which the emissions mix back into the surface layer, and the persistence of the smoke in the air shed.

This study analyses the smoke dispersion and regional health impact on population of three fire events of the last decade: the 2006 alpine fire, the Kilmore East fire of Black Saturday (8^{th} February 2009), and a high intensity prescribed burning event in the Huon Valley, Tasmania in April 2010. Relative health impact was assessed by combining the mean daily surface PM2.5 concentration from smoke during the duration of each event, with population density and the mortality risk factor of 1% increase in mortality per 10 $\mu g\ m^{-3}$ increase in PM2.5 concentration. The greatest health impact was from the 2006 alpine fire, which burned 1.1 Mha over a period of 60 days. Smoke from the fire significantly impacted all of Victoria, including the Melbourne air shed, and producing a risk equivalent to an increase in mortality of 84. This was largely due to the long duration of the event which led to widespread smoke dispersion that reflected seasonal climatology. In contrast, the impacts from the Kilmore East fire and the Huon Valley prescribed burning events were minor, primarily because smoke did not impact regions of high population density and the events were of short duration and therefore determined by the weather of the day. All events emitted large amounts carbon to the atmosphere; however the size of the emission was not a reliable indicator of risk to health.

Prescribed burning is extensive, it averages approximately 70% of the annual fire area in Victoria, and is confined to a relatively short season. While individual fires are small and short lived, collectively they are a large distributed source and may function similarly to a single large protracted wildfire event. The policy to increase the current rate by 250% to 400 kha per year therefore will pose significant challenges for regional managers if PM2.5 impacts on population health are to be avoided.

Keywords: *Biomass burning, wildfires, fuel reduction burning, transport modelling, smoke hazard*

Smoke impacts from prescribed burning in Victoria; developing a risk climatology

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Abstract: Following an increase in the frequency of extreme fire weather in recent years and the subsequent loss of life and damage to property, fire agencies in Australia are under pressure to increase fuel reduction burning. However, at the same time, there is an increasing pressure to reduce the risk of population exposure to smoke. Reconciling these competing demands is a major challenge.

Currently, wind speed and direction are the main guides used by agencies for estimating regions at risk from smoke plume strikes. However, plume dispersion models and computing resources are now sufficiently developed so that the risk to towns and cities from planned fuel reduction and agricultural fires can also be assessed using these tools. This is of particular relevance in north central Victoria, Gippsland and the Riverina where there is a need to identify those areas of forest and farmland most likely to pose a smoke hazard to nearby towns during the autumn and spring burning seasons.

In this paper, we introduce a numerical modelling system which can be used to undertake an assessment of the risk to communities resulting from smoke generated by fuel reduction burning. The paper demonstrates how the system can be used in an inverse modelling mode to investigate the relationship between sensitive receptor- and upwind source regions. Using the Ovens Valley in north-eastern Victoria as an example, we apply the CSIRO dispersion model, The Air Pollution Model (TAPM) coupled to the CSIRO Chemical Transport Model (CTM) to simulate the dispersion of PM2.5 emitted daily between 11:00 and 16:00 during April 2009 from each 3 km x 3 km grid cell in a 50 x 50 cell domain centred on Harrietville. From these data we can assess the relative impact of each source cell on any receptor cell within the domain. Taking the towns of Myrtleford, Harrietville and Mt Beauty as test cases, we find that the greatest likelihood of smoke impact is from fires close to the receptor cell, however more distant sources are also significant, with the strongest located on the valley slopes. Vegetated source areas in the bottom of the valleys and on ridges have least impact. Harrietville and Mt Beauty, which lie in different valleys, nevertheless have similar source risk distributions, in contrast to Myrtleford, which lies downstream of Harrietville on the Ovens River, and has a totally different source risk profile. Significantly, there is no indication of a prevailing flow for any of the three receptor cells. We discuss how the system can be used to provide a self-consistent framework for testing smoke transport screening approaches for use by fire managers for planning prescribed burning schedules.

Keywords: *Fuel reduction burning, transport modelling, screening modelling, smoke hazard, screening tools*

A 40-year mesoscale gridded fire weather climatology for Victoria – an overview

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Abstract: A homogeneous 40-year (1972-2013), hourly interval, 4-km grid climate data-set for Victoria has been generated using a combination of mesoscale modelling, global reanalysis data, surface observations, and historic observed rainfall and temperature analyses. The primary purpose of this data set is for fire management planning.

The numerical modelling approach to generate such a data set avoids the issues of inhomogeneity in both time and space of the observational data. The inhomogeneities in time include changes in observation network density and changes in reporting frequency. The latter is particularly evident during the period of transition from mostly manual synoptic (3-hourly at best) observations to hourly or half-hourly Automatic Weather Station observations that occurred during the 1990's. Spatial inhomogeneity is particularly important from a fire weather perspective due to the lack of observations in areas (e.g. forests, steep terrain) critical to fire management.

The Weather and Research Forecasting (WRF) mesoscale model is used to generate these data. The model is initialised from global reanalysis fields, with three internal nests (36 km, 12 km and 4 km). The outer mesh is nested within 6-hourly global reanalyses. Hourly near-surface forecast fields are combined with Drought Factor fields calculated from the Australian Water Availability Project rainfall and temperature analyses to generate fields of hourly fire danger indices for each hour of the 40-year period. As with any numerical model, there is the potential for both bias errors and also episodic (synoptic) errors to occur. We are assessing these errors and developing methods by which they may be ameliorated.

Outputs provide an almost limitless opportunity for hitherto unavailable analyses – fields of percentiles of Forest Fire Danger Index values, analysis of periods exceeding thresholds at any location, inter-annual and regional variations of fire season characteristics, analysis of prescribed burning windows, of atmospheric dispersion climatologies, of various atmospheric stability measures that might affect fire behaviour, and to assess climatologies of more esoteric mesoscale weather events, such as mountain waves or dry slots, that may affect fire behaviour. The hourly mesoscale data also provide a hitherto unavailable long-period homogeneous data set with which to drive fire spread models, and to consider event-based impacts as well as long-term regional and local-scale bushfire risk..

***Keywords**: Fire weather climatology, Mesoscale modelling, Victoria*

Characterising forest wind profiles for utilisation in fire spread models

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Abstract: Fire behaviour is strongly affected by wind speed and direction. Wind affects fire spread rate bending the flames closer to unburnt fuel, increasing the rate of combustion and by blowing embers ahead of the main fire front lighting spotfires. Stronger winds blow flames forward, lowering the flame angle and subsequent distance between the flame and the fuel. In open areas there is typical a logarithmic vertical wind profile; winds become faster as height increases. However forest vegetation disrupts wind flow, and a logarithmic profile cannot be assumed.

When predicting forest fire spread, wind reduction factors are typically used to reduce open area wind speeds to the more sheltered sub-canopy winds that directly affect fire spread. These methods typically assume a consistent vertical wind profile that does not change with wind speed. In this study we investigated these assumptions. We characterised the variation in wind speed at different heights in different vegetation types and at different open area wind speeds. To do this, we used cup anemometers to measure the horizontal wind speed at different heights in four differently structured forest areas. Our results show that the use on a single wind reduction factor is a gross over-simplification; horizontal wind speeds can vary by a factor of three depending of the height above ground. We have also found that even for a given height, the wind reduction factor can vary by a factor of two or more depending on the strength of the winds in the open. This is in addition to a factor of 10 or more variation in wind speed between different vegetation types.

The variation in wind speed in different vegetation type, height above ground and wind speed in the open means that there is potentially a large margin of error in predicting fire behaviour using wind speeds measured or forecast for 10 m in the open for fires in forests or shrublands. Some strategies for improving estimates of wind speed for fire spread prediction are discussed.

Keywords: *Fire behaviour, fire spread rate, vegetation structure*

Simulating bushfire risk in South Australia with PHOENIX (Rapidfire) gridded fire simulations

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Abstract: The PHOENIX Rapidfire bushfire characterisation tool, developed by the Bushfire CRC and the University of Melbourne, has been used in Victoria and NSW for the simulation of going bushfires and to assess landscape fire scenarios for several years. As part of a project to implement and evaluate the PHOENIX tool for use in South Australia a landscape scenario has been tested. For this study, grids of several hundred individual fires were generated, evenly spaced at 2 km across the case study landscape in the Adelaide Hills. PHOENIX simulated each fire ignition in a grid individually and accumulated the output data for all fires in a dataset. The dataset contains a spatial grid for the study area and statistics for each grid cell, such as frequency of fire impact, likelihood of asset loss, fire intensity, and ember impact. After an initial control run without landscape treatment, several simulations with supplementary fire histories for different fuel treatments in the study area were modelled in PHOENIX. The output data for each simulation run was captured in a separate output dataset for each of the modelled fuel treatment scenarios.

For this study we designed a number of scenarios to assess PHOENIX use in the validation and testing of strategic planning. A ten-year prescribed burning regime for an area in the Adelaide Hills was modelled, with variations in applied fuel treatments. The output data was used to produce Impact Density maps for the study landscape which show areas of high fire impact. These density maps were subsequently plotted against each other to produce Difference Layers to highlight areas where fire impacts have changed after the application of different treatments. We also produced Ignition Threat maps. These maps show ignition points in the fire-grid that are more likely to result in large, high impact fires. In addition to producing impact density and ignition threat maps, we used the data to calculate the spread of fires between different zones in the study landscape to assess the effectiveness of ecological treatment buffers. Some of this data was used in the validation of an economic trial (INFFER model).

A comparison of the density plots generated for the different supplementary fuel treatments showed clear changes in theoretical impacts on the study area. There was a reduction of theoretical fire impacts in some of the most severely affected areas in the control scenarios through the application of prescribed burning. A comparison of Ignition Threat maps for the different treatment scenarios also showed a reduction of the ignition threat in some areas after the application of fuel treatments. As only limited weather data was used in this pilot study, results are not representative of the theoretical fire impacts for the study landscape under multiple weather conditions. In future experiments, a wide range of weather scenarios (different fire danger ratings, temperatures, wind directions and speeds) will aid in producing more representative high impact likelihood maps for a study area. Using PHOENIX output from gridded fire scenarios, landscape treatment options, such as impact reduction through proposed prescribed burning, can thus be evaluated.

Keywords: *Fire spread modelling, bushfire risk*

Coupled numerical simulations show a fire changes the weather forecast

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Abstract: Fire behaviour models are increasingly being used by fire managers in real time, and in future years and decades this use will grow. Operational models presently in application in Australia predict fire spread and other elements of fire behaviour using simple weather variables as input, but they do not include feedback from the fire to the atmosphere. However, it is well recognised that the heat and moisture generated by a fire affects the local weather, which usually manifests as pyro-convective cloud development and modification of wind strength and direction in the fire's vicinity. The interactions between a fire and the surrounding atmosphere can cause feedback loops that affect fire behaviour. What is less well understood is the physical processes that lead to these feedbacks, how and when such feedbacks will occur, and of what magnitude they will be, yet these factors could be of critical importance to fire-ground operations and to firefighter safety. The question, therefore, is what are the appropriate weather inputs for operational fire models to use?

We have run coupled simulations of Australian bushfires using the coupled fire-atmosphere model WRF-Sfire. The simulations have been run in feedback on and feedback off mode in order to assess the impact of a fire on the surrounding atmosphere. The results show significant changes to the mesoscale atmospheric structure as a result of the energy released by a fire. A number of interesting features have been seen in the simulations. Fire plumes interacting with the vertical atmosphere can entrain air from higher levels downwards to the flaming area. Since this air has differing properties to the near surface conditions and is usually drier and associated with higher wind speeds, there are subsequent impacts on fire behaviour. The simulations show that cold fronts can be relocated and strengthened in response to a nearby fire, thus altering the timing of a change in wind direction. In addition, coupling between the fire and atmosphere at a slow moving front produced a large, long lived vortex adjacent the head fire. High temporal resolution simulations showed a dynamic rate of fire spread in response to fire-atmosphere interactions and significant changes to fire spread and fire area due to convergence of the fire-modified winds.

The results show that in certain weather situations, uncoupled simulations will not provide a complete representation of fire behaviour. These results are thought provoking for the current approach to fire weather forecasts and fire behaviour predictions in Australia. Fire weather forecasts focus on a near-surface point forecast of wind, temperature and relative humidity, following the McArthur framework. The simulation results, especially when considered in combination with case studies that examine the meteorology of unusual fire events, show that the three dimensional structure of the atmosphere will determine how a fire behaves.

Current fire behaviour predictions use simple wind inputs (chiefly based on a 10 metre height) without recognition of the fact that it is the fire modified winds which propagate the fire front. These fire modified winds can be markedly different in strength and direction to the unmodified environmental winds. The scale of the feedbacks in the simulations shows the critical need for these elements to be incorporated into operational planning at fire events and strategic planning in the fire science community. Development of robust operational models is necessary, and although the process of fire-atmosphere coupling and feedback behaviour remains poorly understood, it is critical information in order to mitigate against the impacts of bush fires and minimise risk during fuel reduction burns. The Australian fire science community is currently presented with the opportunity and the challenge to design, develop, and implement fire behaviour simulation models that contain appropriate and comprehensive meteorological inputs.

Keywords: *bushfire modelling, coupled fire-atmosphere numerical simulations, WRF-Sfire, fire-atmosphere interactions*

The effect of fire channelling on fire severity in the 2009 Victorian fires, Australia

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Abstract: Empirical studies of the 2003 fires in Canberra have highlighted a phenomenon called fire channelling, whereby a fire spreads rapidly laterally across lee-facing slopes, thus increasing the rate of spread and the power of the fire. Analyses of wind, terrain and fire data have identified thresholds in slope and aspect relative to the wind, which define necessary conditions for the phenomenon to occur. It is expected that areas affected by fire channelling will burn with high severity. Separate empirical analysis of fire severity patterns in the Victorian fires of 2009 identified higher prevalence of crown fire on leeward slopes as compared to that on windward slopes.

In this study, we reconcile these observations by using the thresholds to identify where fire channelling was likely to have occurred in the 2009 fires, and reanalysing the severity patterns to quantify the extent to which high severity corresponded to the identified fire channelling prone areas. The sample is 4500 regularly spaced points (500 m separation) from four time periods within four fires.

Fire channelling prone parts of the landscape were identified using a binary function $\chi(\sigma,\delta)$, which depends on a threshold slope σ and a threshold aspect discrepancy δ. Fire channelling prone parts of the landscape were defined as those satisfying $\chi(\sigma,\delta) = 1$, with other parts of the landscape characterized by $\chi(\sigma,\delta) = 0$. Values of $\chi(\sigma,\delta)$ were calculated using three different DEM resolutions: 30 m, 90 m and 240 m. In each case a binary grid was obtained across the landscape, which was then used as a predictor of fire severity. Initial analyses considered $\chi(\sigma,\delta)$ as the only predictor of fire severity, but subsequent analyses followed a full model selection process as was done by Price and Bradstock (2012), though in this case with $\chi(\sigma,\delta)$ replacing aspect. This approach identified the best model and supported alternatives, including testing all two-way interactions between variables. The best model obtained in this way was compared with the model developed by Price and Bradstock (2012) (i.e. with aspect).

The analyses revealed that locations identified as prone to the fire channelling phenomenon were more likely to experience crown fire, and that this effect was most obvious at larger spatial scales. At the largest spatial scale considered, crown fire occurred in 27.2% of fire channelling prone points and 20.5% of non-fire channelling prone points (33% greater). The binomial regression analyses also indicated that when fitted on its own fire channelling proneness was a significant predictor or fire severity. Overall, the effect of fire channelling on fire severity was substantial and amounted to an 11% increase in crown fire likelihood. Given that the analyses entailed a comparison with all parts of the landscape, including windward slopes where the highest likelihood of crown fire would normally be expected, the effect is very important.

Combined with information arising from other extreme bushfires, including the 2003 Canberra fires, the analyses considered here suggest that fire channelling may be a common phenomenon in large and intense fires. The fire channelling phenomenon therefore poses some serious challenges for firefighting, fire spread prediction, the management of environmental assets and risk planning. Given the effects of fire channelling on fire severity demonstrated by this study, this will be particularly pertinent in high-value water catchments. The results of the analyses also have significant implications for the management of soil erosion and biodiversity conservation in rugged terrain after large fires.

Keywords: *Fire severity, fire channelling, Black Saturday*

Wildland–urban interface (WUI) fire modelling using PHOENIX Rapidfire: A case study in Cavaillon, France

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Abstract: In parts of the world with Mediterranean type climates, periodic wildfires are part of natural processes. Where such fires impinge on populated areas, there is the potential for significant losses of lives and property. The interface between vegetated areas and human settlements is described as the Wildland Urban Interface (WUI) and is typically where most wildfire losses occur. The threat of fire is becoming an important issue due to increasing populations and the potential for increased fire frequency with climate change. Understanding how wildfires behave in and adjacent to the WUI is important, as it can enable appropriate fire preparedness and response actions to be taken. Dynamic fire spread simulators are widely used to characterise large-scale fires to provide rapid predictions of potential fire spread and impacts, however these scales are generally much greater than those of interest in the WUI. There are currently few options for rapidly characterising fire in the WUI.

PHOENIX Rapidfire (PHOENIX) is a wildfire simulator designed to characterise large, fast moving fires in Australia. It is unique in that it incorporates the contribution of firebrand transport and ignition to fire spread. We present a case study where PHOENIX is evaluated as for fine scale WUI fire spread prediction using a fire that occurred in 2012 in Cavaillon, France. This small fire burnt a total of 33 ha in heterogeneous fuels and hilly terrain, which resulted in a variety of impacts within the urban area. A significant feature of this fire was that spotting was observed to be an important part of fire spread; embers were launched from successive ridge tops, carried by winds to ignite fires in adjacent gullies that then ran up subsequent slopes.

PHOENIX requires inputs of fuel, topography and weather. The fuel at Cavaillon was surveyed at a high resolution (1 m) and defined using the Fire Paradox fuel classification. These classes were converted to equivalent fuel loads (t/ha) for different fuel strata as used in PHOENIX. The spotting and ember module of PHOENIX was designed for long distance (>200 m) spotting. Subsequently the spotting model thresholds were manually re-calibrated to provide a comparable spotting pattern to those observed at Cavaillon. Weather inputs were sourced from a nearby automatic weather station. Simulations of fire spread were run at resolutions of 5, 10, 15, 20 m.

Observations of the Cavaillon fire supplied by the local fire brigade were used to reconstruct the actual fire progression. A simulation of the fire using the best data available was compared to the observed perimeter at 18:00. PHOENIX was effective in predicting spread in the WUI, however testing against other fire events is required before its widespread use.

The simulation of small scale spotting appears to be a necessary step in the simulation of such fires where it is a key spread mechanism. In addition modelled ember densities can be used to predict asset impacts, which can supplement standard intensity threshold approaches. The ability to evaluate fire spread characteristics at the WUI scale would provide significant opportunities to estimate impact risk, reconstruct fire behaviour, undertake vulnerability modelling, evaluate fire mitigation strategies and assist suppression planning. The results of our investigation indicate that further research in this area is warranted.

Keywords: *Fire behaviour, fuel types, PHOENIX Rapidfire, wildfire reconstruction, wildland-urban interface (WUI).*

Building Fire Impact Model

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Abstract: The aim of the Building Fire Impact Model (BFIM) is to study the impact of human intervention in a bushfire situation, focusing on the peri-urban communities. The model resides within the Fire Impact and Risk Evaluation Decision Support Tool (FireDST) which simulates fire conditions (Bushfire CRC, 2013). The BFIM recognises that occupants can prepare their house to withstand a bushfire, and if such an event occurs, they can defend their house and may reduce total house loss in the bushfire. To take into account the large uncertainties associated with human intervention, the BFIM was designed to be a probabilistic model, i.e. it uses random variables to represent the main characteristics of occupant intervention. To deal with the complexity of such a model, a mathematical technique called Probabilistic Event Trees (PET) is utilised. In this technique events are represented by the nodes of a mathematical tree and the probability of these events occurring are the tree branches. The conditional dependency of variables is represented by their relative location in the tree.

The BFIM consists of two PETs. The first PET simulates occupant intervention to defend their house from ember attack and possible help from neighbours and the rural fire brigade. The ability of occupants to defend a house depends on their preparation and the preparation of the house to withstand the fire. Occupant preparation comprises purchase of fire-fighting equipment, undergoing training, conducting regular drills, development of an evacuation plan, etc. House preparation involves activities such as cleaning gutters, cutting trees and grass surrounding the house, etc. A series of occupant characteristics are used to assess their efficiency in fighting the ember attack. This tree also calculates the impact of wind speed on the house. Houses damaged by wind/debris during the fire have a higher probability of being ignited by an ember attack.

The second PET calculates the impact of radiation in 'house-to-house' fire spread. This tree examines the impact that houses ignited in the first PET have on nearby houses. The main variables to consider in this part of the model are wind damage to a house, proximity of a house to a neighbouring ignited house and the number of neighbouring houses burnt by the bushfire. An important problem also considered in this tree is 'smoldering embers'—embers that penetrate the house through the roof and slowly burn flammable material due to lack of oxygen—which can results in house loss long after the fire front has passed through the region. Wind and wind damage to the roof increase the danger from this type of ember attack process.

To simulate the dynamic characteristics of these issues, the two PETs are solved sequentially: results of the first PET are used to set up the correct fire conditions for solution of the second PET. For this reason the FireDST simulation model is run three times (passes) for a region. In the first pass, the model calculates the fire conditions in the region of interest and returns the number and location of houses potentially impacted by the fire. In the second pass, the first tree of the BFIM is solved to calculate the impact of human intervention. This sets up different fire conditions and hence FireDST recalculates the number of houses burnt under the new conditions. In the third pass, the second tree of the BFIM is solved to assess house-to-house fire spread. Some houses with a high probability of being 'saved' in the second pass can be reclassified as having a high probability of being 'burnt' after the third pass has been completed.

To illustrate the model, an example case based on the Kilmore bushfire that occurred on 'Black Saturday' (7 February 2009) is provided. Results show that human intervention to fight the fire threatening a house can make a substantial difference to the number of houses burnt.

Keywords: *Bushfire risk, fire spread, ember attack, suppression, human intervention.*

Mapping of Australian Fire Weather Potential: Observational and modelling studies

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Abstract: Indicators of fire weather potential are used by fire management agencies to assess fire weather danger in order to issue public warnings, ban the lighting of open fires, and also boost procedures to mitigate the consequences of a bushfire if such an event occurs.

The most widely used fire weather danger indices in Australia are the McArthur Forest Fire Danger Index (FFDI) and the Grass Fire Danger Index (GFDI). These indices can be calculated at weather stations using measurements of weather variables and fuel information. The planning and emergency authorities, however, require the spatial distribution of these indices over the whole country. In this paper we present a methodology to calculate the spatial distribution of the most widely used fire weather danger index in Australia: the FFDI. In particular we are interested in the long-term trend of extreme values of the FFDI. This indicator of fire weather conditions is assessed by calculating the return period (RP) of its extreme values by fitting extreme value distributions to records of FFDI at a subset of 38 Bureau of Meteorology (BoM) automatic weather stations around Australia. The spatial distribution of the return period was obtained by applying an advanced spatial interpolation algorithm to the recording stations measurements. One of the limitations of this approach is that is does not take into account the impact of climate change on the long-term fire weather potential. To overcome this issue, we present a methodology to calculate RP of FFDI using climate simulated (modelled) data.

Comparison of FFDI based on interpolated data from observational studies with FFDI calculated from climate model simulations for the same period (current climate), shows that both models produce similar patterns of FFDI distribution. Both models show that the highest FFDI over large parts of southern Australia occurs during the summer months whilst in northern Australia the highest values occur in spring. The results also show that the FFDI in eastern Australia, the most populated region of the country, is higher inland than in the coastal areas particularly during spring and summer.

These results give us confidence that we can use climate model simulations to study the trend of FFDI extremes in the final part of the 21st century.

Keywords: *Bushfire risk, fire weather, climate model simulations, fire forest danger index.*

A fire spread index for grassland fuels

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Abstract: Fires in grasslands occur throughout the temperate parts of the globe and in some cases, such as was seen in the 2005 Eyre Peninsula (Wangary) fires, can have significant impacts. To address these issues a number of different models for predicting the rate of spread of fire in grasslands have been developed. In this paper we introduce and discuss a novel index, which incorporates fire weather information and relates to the rate of fire spread in grassland fuels. This so-called *spread index* has the following form:

$$S_{\alpha,\mu}(U, FMI) = \frac{\alpha \max(1, U)}{FMI + \mu},$$

where U is the wind speed (km h^{-1}) and FMI is the fuel moisture index, defined by temperature T (°C) and relative humidity H (%) as:

$$FMI = 10 - 0.25(T - H).$$

The spread index model has two parameters, α and μ. The parameter α serves as a calibration constant that transforms values of the spread index into values that can be interpreted as rates of spread (in km h^{-1}), whereas the parameter μ acts to temper the growth of the spread index as $FMI \to 0$, and can be thought of as representing an intensity dependent indraft wind that counters the prevailing winds at the head of the fire. It is found that the values $\alpha = 2.4$ and $\mu = 6$ provide for reasonable overall performance.

The performance of the index in predicting rate of spread was evaluated through the use of three datasets. The first of these comprises data recorded at Port Lincoln Airport (SA) surrounding the disastrous Wangary Fire (10-11 January 2005). The second is more representative of moderate summer conditions and is comprised of data recorded at Canberra Airport (ACT) in January 2007. The third dataset comprises information relating to twenty significant historical wildfires. These datasets were used as the basis for comparison of the spread index with an established model for grassfire rate of spread (the CSIRO Grassland Fire Spread model).

The fire spread index was found to deliver rate of spread predictions that are practically equivalent to those derived from the established model. On average the differences in rate of spread predictions derived from the spread index and the CSIRO model were 0.2 – 0.3 km h^{-1}, with the biggest differences encountered during the most extreme fire weather associated with the Wangary fire. While neither model did a particularly good job of reproducing the estimated rates of spread of the historical wildfires, in the case of the most extreme fire behaviour during the Wangary fires, the spread index was found to produce the better rate of spread estimates. Overall, given the vagaries of estimating field values for rate of spread and the lack of experimental data for fires burning under extreme conditions, the simple, linearly-structured spread index was found to give reasonable estimates of rate of spread. Indeed, such estimates were not substantially different to those delivered by the nonlinear CSIRO rate of spread model.

These results have implications for the parsimony of fire behaviour models; in particular they suggest a number of conceptual and pedagogical simplifications that could be made with only minimal changes in model performance. The spread index is also briefly considered in the context of a possible unification of fire spread models across different fuel types.

Keywords: *Grassland fire spread, fire weather, wildfire*

Modelling fire line merging using plane curvature flow

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Abstract: The merging of two lines of fire is a relatively common occurrence in landscape fire events. For example, it can arise through the coalescence of two wildfires or when a prescribed fire meets a wildfire as part of suppression efforts. When two fires approach one another, the effects of convective and radiative heat transfer are compounded and high rates of spread can arise as a result. This is particularly the case when two oblique lines of fire meet at some acute angle - the point of intersection on the newly merged fire can advance rapidly. This case was investigated recently by Viegas et al. (2012), who devised a simple analytical model to emulate the effects of energy concentration between the two merging fire lines. In this paper, we present a more geometric approach by considering the evolution of the merged fire as the flow of a plane curve with a normal speed that depends on the curvature of the fire front.

Specifically, we formulate the curvature flow equations in terms of a time-varying graph $y(x,t)$. The resulting evolution equation is a quasilinear degenerate parabolic second-order partial differential equation:

$$\partial_t y = \sqrt{1+(\partial_x y)^2} + \frac{\epsilon \partial_x^2 y}{1+(\partial_x y)^2}.$$

The evolution of the merged fire lines is then modelled by solving an associated initial value and boundary value problem, where the initial conditions are taken $y_0(x) \approx |x| \tan\theta$. The θ here controls the initial angle between the two merged fire lines.

Parametric variation of the curvature dependence (via the parameter ϵ) is investigated, and the resultant geometric evolutions of the fire front are compared with the experimental observations of Viegas et al. (2012). The curvature flow simulations were able to capture a number of features that were observed by Viegas et al. (2012). In particular, the model was able to reproduce the ‘rotation’ of the two fire lines noted by Viegas et al. (2012) and was able to account for the qualititative rate of spread behaviour observed in connection with the rapid advance of the point of intersection of the merged fire lines. This so-called jump velocity profile was characterised by very high initial rates of spread, immediately after the fire lines merged, and then a gradual slowing of the rate of spread approaching a quasi-steady value.

Further theoretical aspects of plane curvature flows and their more general application to fire front modelling are discussed and a number of improvements to the model are suggested.

Keywords: *Plane curvature, evolution equations, normal flow, fire merging*

Examination of wind speed thresholds for vorticity-driven lateral fire spread

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Abstract: Recent work has demonstrated that under conditions of extreme fire weather, bushfires burning in rugged terrain can exhibit highly atypical patterns of propagation, which can have a dramatic effect on subsequent fire development. In particular, wildfires have been observed to spread laterally across steep, lee-facing slopes in a process that has been termed 'fire channelling'. Fire channelling, in turn, has been associated with serious escalation in fire activity and the development of pyrocumulonimbus storms. Coupled fire-atmosphere modelling using large eddy simulation has indicated that the fire channelling phenomenon occurs in response to fire-induced vorticity on the fire's flanks in the immediate lee of a ridge line. In this paper we extend previous modelling, using the WRF-Fire coupled fire-atmosphere model, to specifically consider the effect of wind speed in generating the fire-induced vorticity necessary to drive the lateral spread associated with fire channelling.

We examine the behaviour of simulated fires on leeward slopes under different wind speed regimes, which are characterised in terms of a reference wind speed U_0. The topography is taken to be an idealised triangular mountain with a north-south oriented ridge line. The windward and leeward slopes are taken to be $20°$ and $35°$, respectively, and the height of the mountain is approximately 1 km. Initial and boundary conditions are taken in the form of a vertical wind profile that has a uniform horizontal (westerly) wind field of constant speed U_0 at 200 m or above, and decays quadratically for heights below 200 m, to zero at the surface level, maintaining its westerly direction throughout. Moisture is assumed to be absent throughout the profile and potential temperature is assumed to be a constant 300 K. The reference wind speed U_0 is prescribed values of 0, 2.5, 5, 7.5, 10 and 15 m s^{-1}.

The simulated fire spread under each of the wind speed regimes was examined for evidence of the occurrence of rapid lateral spread across the leeward slope. Under the two lowest wind speed regimes the fire did not exhibit any atypical lateral spread, in stark contrast to the two highest wind speed regimes, in which the simulated fires readily exhibited significantly faster lateral spread. The results suggest the existence of a threshold wind speed, below which the prevailing winds are too weak to drive the vorticity-generating interaction between the wind, the terrain and the fire's plume, so that no atypical lateral spread occurs. The model simulations further suggest that this threshold occurs for wind regimes characterised by $U_0 \approx 5$ m s^{-1}.

The modelling results are also discussed in connection with some recent laboratory-scale fires examining the same effect. The fire behaviour in both cases was found to be qualitatively consistent, though issues surrounding the transferability of the results across the different spatial scales involved prevented a more quantitative comparison.

The simulated behaviour of fires on leeward slopes, and the transistion in fire propagation that can occur when prevailing winds are sufficiently strong, highlight the inherent dangers associated with firefighting in rugged terrain. The propensity for dynamic interactions to produce erratic and dangerous fire behaviour in such environments has strong implications for firefighter and community safety. At the very least the research findings provide additional support for the use of well-briefed observers in firefighting operations in complex topography.

Keywords: *Wildfire simulation, fire channelling, wind-terrain-fire interaction*

Atmosphere-fire simulation of effects of low-level jets on pyro-convective plume dynamics

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Abstract: Blow-up fire behaviour can be broadly defined as a rapid escalation in the intensity or forward rate of spread of a wildland fire, and is often accompanied by extreme pyro-convection associated with rapid smoke release and dispersion. Blow-up fire behaviour is difficult to predict and has been linked to firefighter fatalities, making it an important fire management hazard. Byram (1954) compiled the first observational dataset of categorised wind speed and direction profiles associated with blow-up fire behaviour. Low-level jets, varying in height between 30 and 1000 m above ground level (AGL), are a common feature in Byram's wind-profile types. Additional studies have qualitatively discussed how low-level jets can influence wildland fire behaviour and pyro-convective plume dynamics. However, there has been little quantitative testing and analysis of the physical processes linking low-level jets and blow-up fire behaviour.

The principle aim of this study was to use the Advanced Regional Prediction System (ARPS) at high-resolution, with a 50 m horizontal grid spacing, to numerically simulate the sensitivity of the downwind pyro-convective plume dynamics to four of the Byram wind-profile types. The Byram wind profiles tested each contain a low-level jet with different properties. A moderate-intensity grass fire was prescribed in the ARPS model domain using a constant surface sensible heat flux of 30 kW m^{-2} in a 150 x 2500 m rectangle oriented normal to the prevailing wind.

The numerical simulation results indicated that the fire-related atmospheric conditions and large-scale pyro-convective plume structure were sensitive to changes in the low-level jet properties, i.e. wind shear above the jet and the jet height and intensity. However, despite this sensitivity there were some common features in the four numerical simulations. A triangular-shaped fire-perturbed warm air region developed close to the surface downwind of, and extending from, the steady-state parameterized fire. This warm air region was confined spatially by cross-wind inflows that developed due to an interaction of the background winds with the edges of the fire. The horizontal convergence of these cross-wind inflows downwind of the fire marked the starting location of the fire plume. There were considerable updrafts and downdrafts throughout the model domain associated with the pyro-convection.

The heating of air up to several kilometres downwind of the fire would act to preheat fuels, resulting in increased fuel flammability and therefore an enhanced rate of forward fire spread. Additionally, the atmospheric turbulence directly over this warm air region and the updrafts and downdrafts associated with the fire plume would affect the transportation of firebrands downwind of the fire. The downwind transportation of firebrands can ignite spot fires, which enhance the forward rate of fire spread as the spot fires grow and merge with the existing fire front. Through these mechanisms the low-level jet wind profiles can be directly linked with blow-up fire behaviour.

The numerical simulations performed with ARPS were highly idealised and therefore subject to a number of limitations. For example, temporal variations in the prescribed fire intensity and shape, directional wind shear, background turbulence and moist processes were not modelled in this study. However, future work will gradually address these limitations through further numerical simulations using both ARPS and a coupled atmosphere-fire model.

Keywords: *Blow-up fire behaviour, atmosphere-fire numerical modelling, pyro-convective plume dynamics*

High-resolution WRF simulation of fire weather associated with the Mt Cook Station fire

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Abstract: The Mt Cook Station fire was ignited in 100% cured grass by a chainsaw on 16 January 2008. The fire was eventually controlled on 22 January, although mop-up of hot spots continued for several weeks. The fire burned 756 hectares, predominantly in dense stands of wilding conifers and light scrub, making it the largest wildland fire in the South Canterbury Rural Fire District for over a decade. Periods of high intensity fire behaviour were observed during the main fire runs in the dense wilding stands in the 24 hr period following ignition.

The fire weather conditions and synoptic to mesoscale atmospheric processes associated with the Mt Cook Station fire have been examined using weather station data and the Weather Research and Forecasting (WRF) numerical weather prediction (NWP) model. The WRF model was chosen as it is well suited to mesoscale modelling and was nested down to a horizontal grid spacing of 1 km in the inner model domain.

The WRF model results suggest that northwesterly foehn winds, which are a fairly common meteorological feature of the South Island of New Zealand, were topographically channelled down the alpine basin encompassing the fire early on 17 January. The most intense period of fire behaviour, observed at 0530 NZST on 17 January, occurred during the approximately six-hour period when these foehn winds were at their strongest as they descended the leeward slope of the Southern Alps. The WRF modelled winds are in general agreement with observational reports of the wind conditions noted by firefighters at the scene of the fire. However, the wind conditions at the fire's location were considerably different than at Tekapo RAWS, despite being located only 20 km apart.

Verification statistics were calculated for the WRF model results through direct comparison with observational data taken from Tekapo RAWS. WRF was able to accurately reproduce the observed air temperatures and relative humidity, but not the wind conditions and Fire Weather Index. Although inaccurate modelling of wind conditions in rugged terrain is a widely accepted issue, it is less well known how this affects fire weather indices derived partially from the wind speed. The results presented in this study indicate that there can be considerable errors in using both NWP model output and nearby weather station data when attempting to understand fire weather conditions in rugged terrain.

Keywords: *Numerical weather prediction modelling, fire weather, wildland fire behaviour, New Zealand*

Modelling bushfire fuel across South Australia for use in risk assessments & fire management planning

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Abstract: Fire Management planning and risk assessment rely on fuel hazard information as an important input. Fuel hazard is a measure of the amount and arrangement of fuel that is available to be consumed by a fire. Fuel hazard is therefore an important consideration in predicting the propagation of wildfires across the landscape and in managing the risk posed by such occurrences. Current fuel hazard estimation relies on either destructive sampling (the process of cutting, weighing and collecting vegetation) or more commonly visual estimation (using descriptive guides) of each of the surface, near-surface, elevated and bark fuel layers. Combinations of these fuel layer estimates are then used to calculate an overall fuel hazard rating. Estimates from the destructive and visual fuel hazard assessment techniques have been compared and found to be positively correlated, validating the use of visual assessment samples for modelling fuel hazard.

Destructive sampling and visual assessment obviously have limited applicability as they only provide highly localised estimates of fuel load. In this paper we address this issue by considering models for predicting fuel load across the landscape. These models take the form of various regression models and geo-statistical models. A comparison of different fuel load prediction models was undertaken using vegetation type, soil characteristics and other environmental variables as model inputs. The comparison was used to assess the suitability of models to predict fuel hazard and fuel load based on spatial-autocorrelation, vegetation class, time since last fire and other environmental variables, such as topography and soil.

The outputs have been integrated into a spatial surface using GIS allowing the data to be readily usable as part of fire management planning, bushfire risk assessments and fire prediction software.

Keywords: *Vegetation mapping, bushfire risk, fire planning*

Large-eddy simulations of bushfire plumes in the turbulent atmospheric boundary layer

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Abstract: Spot fires are a hazardous phenomenon which can lead to unpredictable fire behaviour and accelerated fire spread. Spot fires occur when firebrands are lofted into strong ambient winds and ignite new fires downwind. Anecdotal evidence suggests that this lofting and transport of firebrands can be responsible for the ignition of spot fires at large distances, up to tens of kilometres ahead of the fire front. A thorough knowledge of the potential for lofting from a fire is therefore desirable in order to accurately predict the fires rate of spread and coverage.

The extent to which firebrands are lofted and transported away from a fire is largely determined by both the intensity of the fire convective column and the strength of the ambient winds. Previous work on the response of fire plumes to background winds has principally relied on theoretical or highly idealised numerical models. Here we use high-resolution three-dimensional numerical simulations, performed with the UK Met Office Large-Eddy Model, to investigate the behaviour of bushfire plumes. We begin by simulating the dry, neutral atmospheric boundary layer for a range of wind speeds. Simulations are run to a quasi-steady state, ensuring that the flow displays realistic turbulence properties. Plumes are then produced by imposing a localised positive surface heat flux anomaly at the model surface. The sensitivity of the size, shape and intensity of the plume's updraft to the interaction between the plume and the turbulent atmospheric boundary layer is explored, with reference to the potential for spotting.

Keywords: *Bushfire plumes, large-eddy simulations*

From "Wildland-Urban Interface" to "Wildfire Interface Zone" using dynamic fire modelling

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Abstract: The interface zone in relation to wildfires has been defined in many ways. Some definitions have been tailored for particular applications. There is no consistent way of defining the interface or demarcating it on the ground. Current definitions are based more on the ease of application rather than the likely penetration of a wildfire into a residential area. There is a need to have a more consistent and relevant definition of the interface zone for planning, warnings and regulations. The reality is that the interface zone at a particular location will vary depending on the weather, fuel, scale of fire and terrain at any one time so these factors should be included in defining the interface zone.

The interface zone has been referred to in several different ways: it has been called the "I-Zone", "Wildland-Urban Interface (WUI)", "Rural-Urban Interface", "Urban-Interface", "Chaparral-Urban Interface" (Radtke, 1983) and possibly others. These names themselves contribute to a level of confusion when talking about exposure to wildfire. Interestingly, all the names are euphemisms for what is really of interest - the interface with wildfire.

The term "interface" implies a zone where residential areas and wildfires will mix. The extent of the wildfire interface is therefore the extent to which a wildfire can penetrate a residential area before it either self-extinguishes or transitions into an urban fire where the progression becomes dominated by structure-to-structure ignition rather than via wildland fuels. It therefore follows that the majority of house loss caused by wildfires would occur in what we propose should be called the "Wildfire Interface Zone" (WIZ).

Dynamic wildfire characterization simulators such as PHOENIX RapidFire (Tolhurst *et al.*, 2008) have provided a means for defining the Wildfire Interface, taking into account potential fire size, intensity and ember density. PHOENIX RapidFire takes into account the spatial and temporal distribution of fuels, fire, weather, terrain, ignition time and location and modifications to fuels caused by recent fires or other fuel modification works and disruptions to fuels caused by roads, rivers, fuelbreaks, and other linear fuel-free areas.

Some preliminary analyses have shown that it is not just the fuel within some set distance (e.g. 40 m, 100 m) of a residential area that affects the probability of house loss by wildfire, but a combination of all the factors that contribute to wildfire behaviour. PHOENIX RapidFire can be used to define the Wildfire Interface Zones based on local fuels, terrain and climate. We therefore propose a new definition of the Wildfire Interface Zone be adopted to replace the concept of WUI:

"The area where dwellings, or flammable material in contact with dwellings, have the potential to be ignited by exposure to any combination of flame, radiation, embers, firebrands or hot gases from a wildfire. It does not include areas only exposed to smoke, ash or charred material from a wildfire.

The extent of the actual Wildfire Interface Zone will depend on the nature of the fuels, weather, topography, seasonal conditions and scale of wildfires in that geographic location at a given point in time, but for planning purposes the extent of the potential Wildfire Interface Zone can be determined for a stated set of conditions."

Keywords: *Wildland-Urban Interface, PHOENIX RapidFire, Wildfire Interface Zone, dynamic fire modelling, ensemble simulation, fire spread model*

Curvature flows and barriers in fire front modelling

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Abstract: In this paper we propose a novel mathematical model for describing the evolution of a fire front. Specifically, for a homogeneous fuel bed of varying height with constant ignition temperature T_{ig} we model the isosurface corresponding to T_{ig}. The intersection of this isosurface with the fuel bed defines the evolving front.

There are three natural processes driving the evolution of the evolving front: radiative heat transfer, convective heat transfer, and heat/mass transfer. These processes clearly depend on the shape of the isosurface in space, and this nonlinear feedback can be understood through the curvature of the isosurface. The model we propose here is a second-order nonlinear evolution equation, where the movement of the front depends on the curvature of the two-dimensional isosurface in three dimensional space in addition to atmospheric, topographic and fuel conditions.

This approach has marked advantages over traditional linear evolution equations of curves, such as those arising from Huygen's principle. Vertical variations in fuel and weather can be more realistically incorporated, as can barriers blocking the progress of the fire. Our second-order model is also more accurate. Evidence to support this comes in the form of previous experimental fire modelling results, which showed that initial corners of a fire front become immediately smooth. Such behaviour cannot be obtained using a quasi-steady speed of evolution, but is, however, consistent with the presence of a curvature term in the speed.

Modelling the fire front as a surface in space rather than a curve in the plane allows us to better incorporate topography and fuel variations and to examine flame height as a fire passes through an urban or rural region. Further, our introduction of free boundaries for the evolving surface is a new approach in the modelling of fire fronts with barriers. The future behaviour of an existing fire could be understood by predicting the shape of the front using our model, but more significantly, the evolving fire front could be controlled and even forced to extintion in a finite time, by constructing an appropriate back burn region or regions that act as free boundaries in the mathematical model.

Our foci in this paper are to describe the new model, compare it with previous approaches to modelling fire front propagation and present a couple of simplified cases that have already been studied from the analytical point of view. We also outline how improvements introduced to the analytical model will allow a better understanding and prediction of fire fronts.

Keywords: *Curvature flow, partial differential equation, free boundary problem, fire front, barrier*

Using wind multipliers to determine local wind speed from modeled regional data for fire spread applications

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Abstract: Wind multipliers are factors that transform regional wind speeds into local wind speeds, accounting for the local effects which include topographical, terrain and shielding influences. Multipliers have been derived in full-scale experiments or in wind tunnels, and are utilized in structural design and environmental applications as described in the Australian – New Zealand Wind Loading Standard (AS/NZS 1170.2). Site exposure multipliers have been considered in many wind-related studies, such as wind loading design for structures, wind energy generation, wind risk assessment, counter terrorism (dirty bombs) and pollution dispersion problems. In these applications, a precise knowledge of the characteristics of the local-scale wind speed and direction are necessary. To quantify the site specific local wind effects, Geoscience Australia has developed an approach to adjust regional wind speed to local (site) wind speed (direction change not considered). This approach employs a Geographical Information System (GIS) technique that utilizes a high resolution digital elevation model and vegetation data to produce spatial information relating to the local wind effects. The approach was used for wind hazard assessment for the Perth region (Lin and Nadimpalli, 2005), and later for a national wind hazard and risk assessment (Cechet et al., 2010).

Provided vegetation is sufficiently abundant and dry, the spread of bushfires is most rapid in windy conditions with low humidity. This highlights the importance of determining an accurate local wind speed in bushfire hazard and spread calculations, where interest in local wind speeds (length scale of order 1 to 10's of metres) and their effect on the natural environment (grasslands and forest) is of chief concern and importance. Fire behaviour models require local scale wind speed and direction data in order to accurately simulate fire spread, particularly in complex terrain. To model site-specific wind for bushfire spread, we have employed the methodology used for the above wind-related studies, and have derived local site wind variation factors (wind multipliers) at 25 metre horizontal resolution for 8 cardinal directions. To examine the utility of these multipliers we have applied them to a case study where the fire spread occurred over both relatively flat grasslands and also over forested and hilly terrain – the 2009 Victorian fires (Kilmore fire). In addition, we have considered three downscaled horizontal resolutions (3.6 km, 1.2 km & 400 metres) of the forecast weather for the day, and have applied the wind multipliers at 100 metre spatial resolution (the average of 16 derived multipliers for the appropriate modelled wind direction).

This paper describes the wind multiplier computational methodology and the application of wind multipliers to bushfire hazard and impact analysis. Wind multipliers are used in this study within a bushfire spread investigation, and their efficacy is evaluated by considering the performance of the fire spread model (PHOEXIX Rapidfire) over time-segments (i.e. fire progression) of the case study fire. We compare fire extent, shape and overlap of our results against the reconstruction of the fire extent carried out during the post-disaster impact assessment for the 2009 Victorian Bushfires Royal Commission (Teague et al., 2010). The analysis also includes comparison of the results of employing the Wind Ninja computer program (Forthofer and Butler, 2007), developed by the Fire, Fuel and Smoke Science Program at the Rocky Mountains Research Centre (U.S.), that computes spatially varying wind fields which simulate both topographic and terrain effects on the wind flow at scales relevant to wildland fire applications.

The initial analysis has determined that it is difficult to reproduce the actual fire spread using the approaches described above. More issues are explored and further improvements are investigated. We discuss the appropriateness of considering surface properties for extreme wildfire simulations (i.e. using 10 metre height wind speeds) where ember generation and fire-spotting ahead of the fire-front plays an important part in the fire spread process. We also explore the use of modelled wind speeds representative of the lower boundary layer to drive the fire spread, which for this case study (large conflagration) provided improved simulations.

Keywords: *bushfire spread modelling, wind multipliers, wind profile, fire spread impacts*

Are the physics we use to model deep-ocean tsunami adequate?

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Abstract: A tsunami is a set a long-period waves generated by a large-scale displacement of the sea surface, which can be caused by phenomena such as earthquakes, landslides, volcanic events, extreme meteorological conditions and asteroid impacts. The very large scale of this initial water displacement compared to the ocean depth allows us to make some major simplifications to the hydrodynamical theory, resulting in the Saint Venant equations (or Shallow water theory). These equations allow us to model shallow water waves, in a non-dispersive theory, over a non-deformable rigid Earth. Although these approximations often result in a reasonable ability to model observed data. However recent well-recorded tsunami observations in various sensor such as bottom pressure sensors, GPS buoys of the previous two main tsunami event (Maule, Chile 2010 and Tohoku, Japan, 2011) have shown that there are some discrepancies which are clearly evident in tsunami waveforms that have propagated over large distances attributed to the compressibility of seawater, the elasticity of the solid earth and the gravitational potential change associated with the sea water mass motion during the tsunami propagation. These discrepancies, of up to 2% in tsunami arrival time, can explain the fact that the reconstruction of the seismological sources using tsunami data (data inversion) differ from the other type of data inversion.

We have developed a new finite difference code for tsunami propagation that allows the inclusion of several effects normally ignored in conventional tsunami simulations - sea floor deformation due to the passage of the tsunami wave, self-gravitation and wave dispersion - in order to show the effect of these forces in the simulations and determine whether they have a significant influence on tsunami propagation. Because some of these effects require the introduction of a spatial convolution at each time step, the computational demands are greatly increased. We show how parallel algorithms can be exploited to significantly reduce the computation time, and compare the results with recent observations of trans-Pacific tsunamis.

Keywords: *Tsunami, Numerical Modelling*

Predictions on arrival times of water of the St. Francis dam break flood using ANUGA

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Abstract: ANUGA software is used to simulate the 1928 St. Francis dam break flood. ANUGA (see https://anuga.anu.edu.au/) is a free and open source software, which is designed to simulate shallow water flows. Our simulation assessment in this paper is based on the arrival times of water at several stations. We use the BreZo hydrodynamic algorithm results of Begnudelli and Sanders ("Simulation of the St. Francis Dam-Break Flood," *Journal of Engineering Mechanics*, Vol. 133, pp. 1200–1212, 2007) to compare with, in addition to measured arrival times of the real event. Note that in simulations, arrival time can be measured with respect to either the water front or water discharge peak. Our simulations are of two types, catchment and detailed.

The catchment type simulation considers the area extending from the dam site to the Pacific Ocean. It has the dimension 81.3 km by 43 km containing the entire 87 km river reach (about domain diagonal) with around 300,000 triangular computational cells. Our results of the catchment type simulation agree with those of measured arrival times of the real event. These measured arrival times of the real event were investigated by a number of researchers, such as, Outland in 1963 ("Man-made disaster: The story of St. Francis Dam", published by The Arthur H. Clark Company). Note that Begnudelli and Sanders computed arrival times of water at specified stations by checking the arrival of water front and the water momentum (discharge) peak. They obtained that the arrival times of water discharge peaks agree more with measured arrival times of the real event than the arrival times of the water front. However, our ANUGA simulation results in the opposite, that is, arrival times in terms of the water front match better with measured arrival times of the real event.

The detailed type simulation focuses on the upstream reach area. It has the dimension 8.1 km by 6.9 km containing 6 km portion immediately downstream of the dam wall and the 4 km reservoir, making it in total a 10 km (about domain diagonal) model. The aforementioned paper by Begnudelli and Sanders reports on shock waves and sloshing behaviour as the dam break flood wave progressed down the initial portions of the valley. In order to fully investigate these phenomena the detailed ANUGA mesh is set up and includes triangular cells down to the size of 100 m^2. Therefore, we have around 161,000 triangular computational cells for this detailed type simulation. Once again, our computational results indicate that arrival times in terms of the water front match better with measured arrival times of the real event rather than water discharge peaks.

These results confirm that arrival time predictions should be viewed with some scepticism unless modellers have accurate values of computational parameters, such as topography roughness, as Begnudelli and Sanders suggested.

Keywords: *St. Francis dam break, ANUGA software, finite volume, flood inundation*

3D tsunami/storm surge inundation modelling using SPH: advantages and challenges

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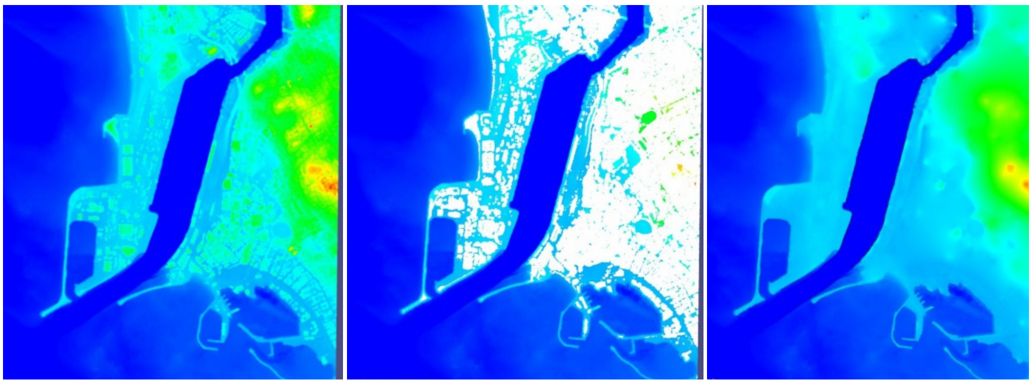
Abstract: Tsunamis and storm surges are catastrophic natural hazards that can impact coastal regions with devastating consequences to life, property and infrastructure such as roads and communication systems. The magnitude of devastation can be significant for heavily populated coastal regions and instances where there is key infrastructure such as the Fukushima Nuclear Plant in the recent tsunami devastation in Japan. The challenges for modelling inundation of such regions include the ability to accurately include infrastructure (static and mobile) to effectively capture the 3D nature of the flow. This is very important because the nature and location of the infrastructure can significantly influence the downstream consequence of the tsunami/storm surge inundation leading to amplification or attenuation of the inundation force and extent. Smoothed Particle Hydrodynamics (SPH) is a fully three dimensional mesh free computational fluid dynamic method that has a significant advantage in free surface flow modelling. It is especially suited for fluid structure interaction problems since the flow and interaction with structures can be resolved in a single code structure. In this presentation the salient steps involved in performing 3D simulations of tsunami/storm surge inundation and the challenges involved are described. These include terrain optimisation involving pre-processing of LiDAR/satellite data, 3D infrastructure modelling, input conditions for the SPH model and visualisation. A hypothetical tsunami inundation event along the Freemantle Harbour is used for the demonstration. The presence of infrastructure on the harbour reduces the impact of the incident wave resulting in similar inundation levels for three incident wave angles of 0, 15 and 30 degrees. The effect of the absence of any infrastructure (not shown here) is compared with these inundation patterns to further ascertain the retarding effect of the structures.



Original LiDAR Non-ground removed Processed for SPH

Figure 1: Re-building of LiDAR data for Freemantle harbor after removal of non-ground data

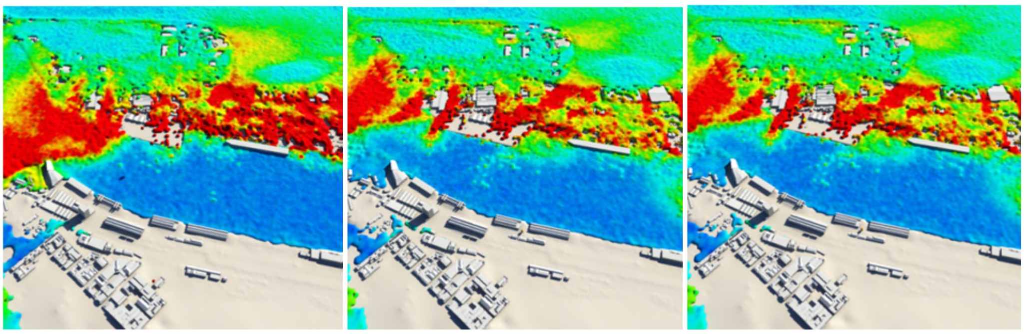


Figure 2: tsunami inundation with wave angle's of 0, 15 and 30 deg incident onto Freemantle Harbour.

Keywords: *tsunami inundation, SPH, 3D simulations, fluid structure interaction*

High Resolution Tsunami Inundation Simulations

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Abstract: In this paper we investigate the high performance computing efficiency of the shallow water software package ANUGA . This package is developed as a collaborative project between the Australian National University (ANU) and Geoscience Australia (GA) and is available as Free and Open Source Software (FOSS). ANUGA uses a shallow water model and approximates the model using the finite volume method based on unstructured meshes of triangles. The geometrical flexibility of unstructured meshes is convenient for tsunami inundation modeling where the tsunami wave source generally consists of long wavelength components, and waves around the coast consists of short wavelengths, which can both be modeled in the same simulation. ANUGA is written in the high level computer language PYTHON. We will present an overview of the model and the numerical method in the early sections of the paper. We will then present our work on parallelizing the ANUGA code, in particular our efforts to obtain efficient simulations using 100s of CPU cores. Our results demonstrate that our PYTHON based software can obtain high efficiency on highly parallel computers. The results presented in this paper demonstrate better than real time simulation of medium resolution (millions of triangles) tsunami models. Our ultimate goal is the solution of high resolution (tens of millions of triangles) simulations in better than real time.

Keywords: *Shallow water wave equations, tsunami simulation, finite volume method, high performance com-puting, python*

On epidemic models with nonlinear cross-diffusion

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Abstract: Modelling and simulation of infectious diseases help to predict the likely outcome of an epidemic. A well-known generic model type for the quantitative description of the epidemic evolution dynamics by an ordinary differential equation is provided by so-called SIR models. These models classify a population into "suscepti-ble" (S), "infected" (I) and "recovered" (R) subgroups. One very early and simple prototype of an SIR-model is due to Kermack and McKendrick (1927). It describes the population evolution by the system of ordinary differential equations

$$\frac{dS}{dt} = -\beta SI, \quad \frac{dI}{dt} = \beta SI - \gamma I, \quad \frac{dR}{dt} = \gamma I,$$

with transmission rate $\beta > 0$ and recovery rate $\gamma > 0$. This equation can be written in general form as

$$\frac{\partial S}{\partial t} = f(S, I), \qquad \frac{\partial I}{\partial t} = g(S, I), \tag{1}$$

where the epidemic interaction dynamics are modeled in the functions f and g. The variable "R" can be dropped since its evolution is already implicit in the equations.

This basic SIR model can be extended by introducing a spatial distribution of both populations. In this contribution, it is shown how the spatial extension can be done by either a continuous or a discrete spatial distribution. For the continuous distribution, the model is typically formulated as a system of reaction-diffusion equations, where the reaction terms describe the local dynamics of susceptible and infected species, and the diffusion terms account for the spatial-distribution dynamics. For a discrete local distribution, the population is typically arranged in a series of patches. Each combination of population-type and patch corresponds to a particular variable. To describe the dynamics between different patches of the same population-type, the ordinary differential equations are extended by diffusion terms, which have an effect that is similar to the heat diffusion in Newton's law of cooling.

The dynamics are the same for continuous and discrete spatial distributions. At each location, both populations are present and interact locally according to an ordinary differential equation that governs the local epidemic interaction-dynamics. In addition, the spatial distribution allows us to model a spatial diffusion, which can be either "self-diffusion" or "cross-diffusion". For self-diffusion, the diffusion rate of each population depends on its particular local variation, whereas for cross-diffusion, the rate also depends on the local variation of the other population. For an SIR model, cross-diffusion is consistent with the phenomenon that the susceptible population avoids areas with an elevated percentage of the infected population.

It is known that diffusion in general and self-diffusion in particular aim towards an equilibrium solution, where the populations are homogeneously distributed. On the other hand, the coupling of diffusion with ordinary differential equations might provoke a nonequilibrium behavior, which is known as Turing instability. The extended SIR model provides a spatial pattern formation that is essentially driven by cross-diffusion.

In this contribution, nonlinear constitutive equations are suggested and analyzed for both self-diffusion and cross-diffusion. In particular, the modelling of cross-diffusion is reconsidered by starting from a basic SIR model, which is extended by either a discrete or continuous spatial distribution. Comparing the discrete model with patches to the continuous PDE model prepares the way for a micro-macro transition, where the continuous model can be deduced from the discrete. This deduction allows us to advance in the development of epidemic models with cross-diffusion. This is further elaborated in the complete version of the paper.

Keywords: *Epidemic model, Cross-diffusion, Reaction-diffusion equation*

Generalised multistability in a SIRWS model of infectious disease transmission

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Abstract: The epidemiological dynamics of diseases for which immunity is not lifelong are challenging to understand. Here we explore a seasonally forced susceptible-infectious-recovered-susceptible model with immune boosting (the SIRWS model) to see whether the model is capable of producing chaotic dynamics.

We pay particular attention to whether the presence of chaos in such a model is unique in initial condition space or whether it exists in conjunction with one (or more) periodic attractors. Our investigations are designed to support the analysis of complex epidemiological behaviour for diseases such as pertussis.

The model is a seasonally forced variant of that presented in Dafilis et al (ANZIAM J 2012; 54: 50-63 doi:10.1017/S1446181113000023). Model parameters were selected from our studies of parameter space, to produce multistable behaviour (Dafilis et al, in preparation). Initial condition spaces were generated by numerically solving the model equations using the CVODE MEX wrapper in MATLAB (Bioinformatics, 2012; 28(8): 1130-1135). Initial conditions were chosen at random and constrained such that $S(0)+I(0)+R(0)+W(0) = 1$ to conserve population size and hence maintain biological fidelity. Periodicity was detected using a variant of a method presented by Taylor, Sherratt and White (J Math Biol, doi:10.1007/s00285-012-0612-z). Chaotic dynamics were detected using an implementation of the 0-1 test for chaos (SIAM Journal on Applied Dynamical Systems 2009; 8: 129-145 doi: 10.1137/080718851) and the Christiansen-Rugh algorithm for the largest Lyapunov exponent of the dynamics (Nonlinearity 1997; 10: 1063-1072).

With epidemiologically and biologically motivated parameterisation of our model, we used the algorithms previously mentioned to detect periodic solutions or chaos, exploring how the characteristic dynamical behaviour varied over initial condition space. We present I vs S slices through this four-dimensional initial condition space as these are of the most biological interest (Figure 1).

The chaotic candidates in model parameter space were shown to have initial condition spaces that were compartmentalised into different sub-regions corresponding to chaotic and periodic attractors, indicative of generalised multistability (shown in Figure 1). The coexistence of chaos and periodic attractors may have implications for our understanding of the complexity of patterns of disease prevalence.

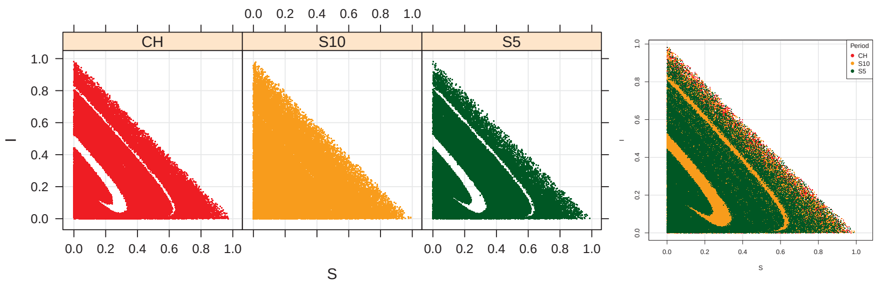

Figure 1: The initial condition spaces for I vs S for chaotic, period 10 behaviour for S, and period 5 behaviour for S, alongside the complete initial condition space representation for the SIRWS seasonally-forced model for a particular multistable parameter set. The regions in space are difficult to distinguish clearly as they extend in four dimensions. This two-dimensional slice through this four-dimensional space shows that both periodic and chaotic behaviour are extensive in initial condition space for this particular model parameterisation.

Keywords: SIRWS model, immune boosting, nonlinearity, chaos

Analysis of Importance of Brief Encounters for Epidemic Spread

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Abstract: Social network research has discovered that in many human networks both the frequency and duration of social interactions approximately follow a power-law with cumulatively short duration interactions being vastly more common than long duration interactions. Conversely it is known that longer duration interactions lead to a greater chance of disease transmission. This article examines mathematically if these briefer, more numerous, encounters are more important to epidemic spread than longer encounters. The focus is on respiratory diseases for which there is evidence that transmission is dominated by close range aerosol transmission.

The method involves mathematically deriving how many people a single infectious person will infect over the course of a day, in a population whose contact durations are governed by a power-law profile. Experimental evidence for use of this profile is cited. The effect of progressively eliminating the shortest and longest links for the network is then studied.

The mathematical analysis is validated by simulating disease outbreaks over a freely available, experimentally obtained high resolution school temporal-contact network dataset.

The results show that while the vast majority of contacts are very short, they should not play a great role in respiratory disease transmission, and that it is the few number of long interactions that dominate the disease spread. An estimate for the factor that the basic reproduction rate for a disease can be reduced by, by culling long interactions, is derived.

This work has practical applications. Firstly it indicates that partial quarantining that consists of cutting long interactions (and not replacing these by many short interactions) should be effective for many diseases. Secondly it shows that when modelling disease spread in a population, a model could be greatly simplified by ignoring quick interactions while not losing a large amount of accuracy.

Keywords: *Epidemics, Networks, Probability, Snowball sample*

Network Centrality and Super-Spreaders in Infectious Disease Epidemiology

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Abstract: So-called "super-spreaders," who are particularly effective in transmitting infectious diseases, are of concern to public health officials. In this paper, we study the phenomenon of "super spreaders" using the Susceptible-Infected-Recovered (SIR) model of infectious disease. In particular, we explore *network centrality measures* as potential predictors of the average number of other people who will be infected by a given node in a social network.

We consider six centrality measures: the *node degree d*, *closeness centrality* C_C, *valued centrality* C_V, *Jordan centrality* C_J, *betweenness* C_B, and *eigenvector centrality* C_E. These measures are correlated to varying extents, with a 0.97 correlation between closeness centrality and valued centrality, but only a 0.14 correlation between Jordan centrality and betweenness.

We report simulation experiments in which the duration of infection is one time-step, and infection begins with a solitary individual. Results are averaged over 1,000,000 simulated runs. We use a varied sample of 15 social networks, and vary the probability q that, given an infected person x and a susceptible person y connected by a link in the social network, the infection spreads from x to y.

In the highly infectious case with $q = 0.9$, the best predictor of the average number of other people who will be infected by a given node in a social network is the betweenness C_B, with an R^2 value of 81.4%. For q in the range 0.5 to 1.0, the product $0.74\ C_B^{0.49}\ d^{1.03}\ q^{0.24}$ has an R^2 value of 87.7%, and this leads to a method for targeted vaccination.

In the less infectious case with $q = 0.05$, the node degree d is the best predictor of "super-spreading." In contrast to Macdonald *et al*. (2012), eigenvector centrality C_E is not a good predictor. This is because the recursive definition of eigenvector centrality sometimes results in it simply highlighting one densely connected network subset, rather than acting as a true centrality measure.

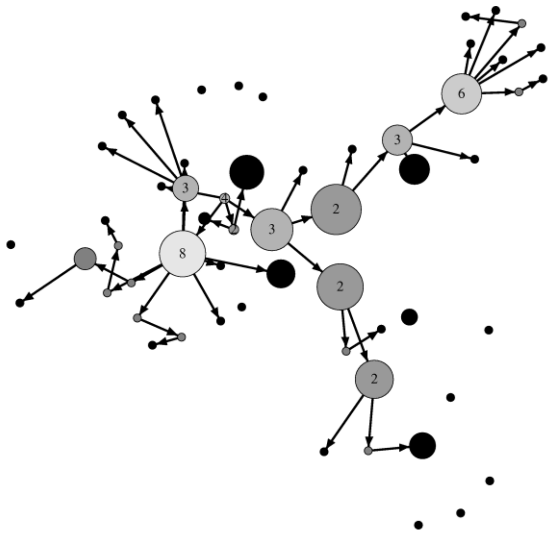

Figure (i). Spread of infection in one social network. Only links along which infection spreads are shown. Node area shows betweenness C_B, which is a good predictor of the number of other nodes infected, indicated with node colour and label. The two light-coloured "super-spreaders" have high betweenness scores.

Keywords: *Networks, epidemiology, SIR model, centrality, super-spreaders*

Modelling the impact of vaccine coverage on maternal measles immunity

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Abstract: Recent measles outbreaks in Australia, Europe and elsewhere are generally associated with sub-optimal vaccine coverage and highlight the need to improve vaccination rates. However, the problem may be more complex than just undervaccination. It is known that maternally derived antibodies may decay more rapidly in infants born to mothers with vaccine-associated immunity compared to infants from naturally immune mothers. In addition, reductions in disease prevalence reduce opportunities for immune boosting in women approaching childbearing age, which may further decrease the length of time that infants are protected by maternal antibodies. Efforts to eliminate measles therefore require an understanding of the influence of historic patterns of population demography, disease prevalence and vaccine coverage on current patterns of population immunity to determine optimal targeting of immunisation.

Modelling is a valuable tool to improve understanding of population immunity and numerous models have been proposed that incorporate either the age or household structure of populations. However, simultaneously including both age *and* household structure in models is challenging using traditional mathematical approaches. We have developed an individual-based model of populations that simulates the birth, death and aging of individuals, as well as couple formation and separation, and movement between households. Calibrated using available census data, our model produces plausible household and family structure and dynamics over multiple decades. As our model explicitly represents individual and household relationships, it is straightforward to capture information on maternal immunity and household-level patterns of susceptibility, exposure and vaccination. The spread of infection is simulated using a parametric model of contact structure that incorporates flexible assumptions about the age assortativity of community contacts and the relative importance of households to disease transmission.

Here, we introduce our model and describe the calibration and validation of the demographic component of the model against Australian population data, the calibration of the disease model to match empirically observed patterns of contact and the epidemiology of a measles-like illness, and the emergent patterns of household susceptibility in pre- and post-vaccination scenarios. Drawing on associations between vaccination and maternal immunity, we explore how patterns of susceptibility change across cohorts born during periods of changing demographic structure, vaccine coverage and disease incidence, and how opportunities for immune boosting vary with household context. We compare the output of our model to that of an existing mathematical model of dynamic households, demonstrating how the simultaneous inclusion of both age and household structure captures more realistic patterns of household susceptibility, and facilitates evaluation of a broader range of scenarios.

In future work, we aim to compare the effectiveness of various proposals to improve population immunity, such as changing the timing of childhood primary and booster doses, and the possible requirement for additional vaccine doses to adolescents and/or women of childbearing age.

Keywords: *Infectious disease, measles, maternal immunity, vaccination, individual based models*

Modelling the seasonality of respiratory syncytial virus in young children

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Abstract: Respiratory syncytial virus (RSV) is a major cause of acute lower respiratory tract infections in infants and young children. The transmission dynamics of RSV infection among young children are still poorly understood (Hall et al., 2009) and mathematical modelling can be used to better understand the seasonal behaviour of the virus. However, few mathematical models for RSV have been published to date (Moore et al., 2013; Weber et al., 2001; Leecaster et al., 2011) and these are relatively simple, in contrast to studies of other infectious diseases such as measles and influenza.

A simple SEIRS (Susceptible, Exposed, Infectious, Recovered, Susceptible) type deterministic ordinary differential equation model for RSV is constructed and then expanded to capture two separate age classes with different transmission parameters, to reflect the age specific dynamics known to exist for RSV. Parameters in the models are based on the available literature.

In temperate climates, RSV dynamics are highly seasonal with mid-winter peaks and very low levels of activity during summer months. Often there is an observed biennial seasonal pattern in southern Australia with alternating peak sizes in winter months. To model this seasonality the transmission parameter $\beta(t)$ is taken to vary sinusoidally with higher transmission during winter months, such as in models presented in Keeling and Rohani (2008) for infections such as measles and pertussis:

$$\beta(t) = \beta_0[1 + \beta_1 \sin(\frac{2\pi t}{52})]. \tag{1}$$

This seasonal forcing reflects increases in infectivity and susceptibility thought to be due to multiple factors including increased rainfall, variation in humidity, and decreased temperature (Cane, 2001; Weber et al., 1998).

Sinusoidally forced SIR-type models are known to support complex multi-periodic and even chaotic solutions. For realistic parameter values, obtained from the literature, and depending on the values selected for β_0 and β_1, the model predicts either annual peaks of the same magnitude, or the observed biennial pattern that can be explained by the interaction of the forcing frequency and the natural frequency of the system. This behaviour is in keeping with what is observed in different climatic zones.

Keywords: *Mathematical model, infectious disease, respiratory syncytial virus, seasonality*

Developing new pharmacokinetic-pharmacodynamic models of antimalarial activity

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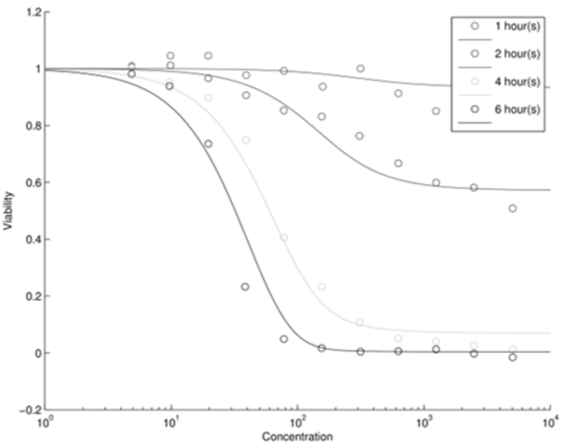
Abstract: Antimalarial drugs form one of the major frontline defences against malaria, yet their mode of action for killing the parasites is not well understood. Pharmacokinetic-pharmacodynamic (PK-PD) models describing the change in parasite burden over time in the presence of time-dependent antimalarial drug concentrations have allowed researchers to interpret data from clinical efficacy studies and revise current treatment guidelines, and consider important questions such as the optimisation of clinical trials of novel therapies and the emergence of antimalarial resistance.

In conjunction with experimental colleagues, we have recently published experimental data which provides compelling evidence that the *in vitro* parasite killing rate is not simply a function of the drug-concentration at that time, but depends upon the *exposure history* of the parasite(s). This data is amenable to analysis with a simple model accounting for cumulative exposure as it was conducted under fixed (time-independent) drug-concentration conditions.

We model the time-to-death distribution through a standard multi-stage ODE model whereby 'non-viable' parasites are only those that have transitioned through all intermediate (non-physical) model states. We first write $\frac{dV_1}{dt} = -k(C)V_1$, where *k(C)* is a concentration-dependent rate, modelled as a sigmoid:

$$k(C) = K_{\max}\frac{C^{\gamma}}{C^{\gamma}+C_{50}^{\gamma}}.$$



We then introduce n sub-stages to explore the time-to-death distribution (with mean $1/k$, independent of n):

$$\frac{dV_2}{dt} = k(C)V_1 - (k(C)\times n)\times V_2$$
$$\vdots$$
$$\frac{dV_n}{dt} = (k(C)\times n)\times V_{n-1} - (k(C)\times n)\times V_n$$

Viability is defined as $\sum_{i=1}^{n} V_i(t)$. The hazard (for death) is exponential for *n*=1, and peaked for *n*>1. As $n\to\infty$ the hazard converges to a δ-function and all parasites have an identical lifespan. The figure shows this model's fit to the viability data for $n = 5$, with concentration employed as the independent variable. The data shows viability for eleven (11) concentrations and four (4) total exposure times (1, 2, 4 and 6 hours).

In the *in vivo* setting however, two factors must be accounted for when modelling drug-accumulation effects: 1) the life-cycle (ageing, reproduction) of the parasites and 2) the time-dependence of drug-concentration (pharmacokinetics). Here we consider extensions to the standard PK-PD model of antimalarial activity that explore how these time-dependent cumulative exposure effects modify parasitological response., in particular killing of parasites within the first few days following treatment.

With a host of public health policy recommendations based on studies where the underlying drug-parasite models have not allowed for cumulative dose effects, it is paramount that we develop an improved understanding of the biological action of antimalarial drugs.

Keywords: *malaria, within-host model, infectious diseases*

Quantifying the relative fitness of two different influenza viruses

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Abstract: Mathematical models are a useful framework with which to examine a pathogen's infection dynamics within a host, and subsequently to gain insight into biological processes that are relevant for that pathogen. Here we fit such a within-host model to viral kinetic data derived from experiments involving co-infection of animal hosts with two different influenza viruses. We analyse the model's parameters in order to assess the relative fitness of one virus compared to another.

Our model describes the infection dynamics of the two co-infecting influenza strains in these experiments, including the dynamics of both infectious and non-infectious virus. Infectious virus is measured using a TCID50 assay which is unable to distinguish the two strains. Total (infectious and non-infectious) viral load is measured using real-time RT-PCR. A pyrosequencing assay measures the relative contribution of each virus to RT-PCR measurements. Using this model, we investigate three different hypotheses regarding the biological source of strain-dependent viral load dynamics: (1) the production rate of infectious virus differs between strains, (2) the average duration of the latent phase of infected cells differs, and (3) the production rate of non-infectious virus differs. We investigate each of these hypotheses independently. An estimated difference in the biological parameter mentioned in either hypothesis (1) or (2) provides support for a within-host fitness difference between strains. However this is arguably not the case for hypothesis (3), as a difference in the production rate of non-infectious virus between strains simply results in a different accumulation rate of non-infectious virus within the host *without* generating strain-dependent fitness.

When a model corresponding to a given hypothesis is fitted to data, although each of the two strain-variant parameters are poorly-estimated, they are correlated in such a way that their ratio is well-estimated. We can therefore use the ratio of these strain-dependent parameter estimates to quantify strain-dependent viral load dynamics. In the case of hypotheses (1) and (2), we also use this ratio to quantify the relative fitness of each strain.

For 6 of the 7 experimental datasets that we analysed, the 95% confidence interval for the ratio of strain-dependent parameter estimates excluded unity, with consistent results across all three different hypotheses for a given experiment. In all experiments, viral load dynamics were reproducible using either a model *with* (hypotheses 1 and 2) or *without* (hypothesis 3) strain-dependent fitness. Our results give no indication as to which hypothesis more precisely reproduces the data, although further observations from the experimental system examining host-to-host transmission of mixed infections support the hypothesis that there are indeed fitness differences between strains.

Our model is unable to differentiate between alternative hypotheses that explain observed strain-dependence in viral load dynamics within individual hosts. While it is possible that these are due to true differences in within-host viral fitness, the model also supports another plausible scenario in which production of non-infectious virus is strain-dependent. This limitation derives from the inability to distinguish between relative proportions of strains comprising *infectious* as distinct from *total* viral load, highlighting limitations in present techniques for virus measurement.

Keywords: *Influenza, within-host modelling, pathogen fitness*

Empirically grounded network models for studying epidemics: what's relevant?

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Abstract: It is increasingly recognised that contact networks are relevant to the transmission of diseases. However, it remains unclear *which features* of contact networks are relevant for modelling epidemic dynamics. The node degree and clustering have both been demonstrated to play important roles. For example, in the case of "scale free" networks, high variability in the node degree distribution is characterised by occasional nodes with many contacts ("hubs"). On these networks epidemics behave qualitatively differently from the standard assumption of homogeneous mixing. Clustering appears to play a role too, by slowing an epidemic and possibly leading to smaller final size. Published results suggest capturing the global clustering coefficient is not enough, especially if clustering is extensive. It appears the specific nature of the clustering is also important. Other features may be important too.

Network models for the study of epidemic dynamics would seem to have several desirable properties for the study of epidemic dynamics. 1) Key network features are solvable (e.g., giant component size). 2) They capture relevant features of networks (e.g., clustering, homophily) although a sufficient list of such features is unknown and probably depends on disease features. 3) Epidemic dynamics are solvable for key quantities (e.g., final size, epidemic duration, infectivity threshold for epidemics to occur) without explicit stochastic simulation of the epidemic (e.g., using a system of ODEs or bond percolation results).

The "configuration model" and generalisations provide a method for simulating contact networks. The configuration model is an example of a "stub model" for which each node is assigned a number of "stubs" (i.e., half edges) equal to its number of incident edges. A contact network is formed by randomly choosing pairs of stubs, without replacement, and connecting them to form edges, until all stubs are used. This technique creates random networks with a given degree distribution. (Strictly speaking it fits the degree sequence.) Generalisations have been described that also fit triangles, cliques, and other subgraphs, by defining node "roles" at each node and connecting corresponding "stubs" and "corners". (The node roles describe the variety of roles nodes play within subgraphs after accounting for isomorphisms.) A key advantage of these models is that the dynamics for SIR epidemics can be written as a system of differential equations, removing the need for extensive simulations.

Exponential random graph models (ERGMs) are another method to model contact networks, and are grounded in hypotheses about social processes underlying network tie formation. ERGMs provide parsimonious models that simultaneously capture many network features relevant to human interaction such as clustering, homophily and social circuit dependence. Unfortunately, studying epidemics on these networks generally requires simulation of contact networks followed by simulation of the disease transmission process on those contact networks.

Starting from empirical contact networks we explore how each of the two network modelling frameworks affects conclusions about epidemic dynamics. For configuration models, we also explore which additional subgraphs might be included to improve the fit with simulated epidemics on the empirical network itself.

We find ERGMs consistently capture clustering better than configuration-type models, but the latter better capture the node degree distribution. The use of ERGMs does not noticeably improve agreement of SIR epidemic results with the empirical network. Including subgraphs of four nodes offers some improvement for configuration-type models. There is no evidence the ability of a network model to better capture k-triangles for $k > 2$ improves agreement with the empirical networks.

Keywords: *Contact network, configuration model, disease transmission, exponential random graph model, ERGM*

Modelling the spread of livestock disease on a national scale: the case for a hybrid approach

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Abstract: An epidemic of exotic disease in a livestock population can lead to substantial economic losses. For example, the projected cost of a foot-and-mouth disease (FMD) epidemic in Australia is in the billions of dollars. This includes the direct cost of eradicating the disease (e.g., movement restrictions, culling and vaccination), and the impact to export markets from the loss of Australia's FMD-free status.

Epidemics can be difficult to study empirically, particularly if a pathogen is dangerous, rare, or simply not present in a country. In these circumstances a model of disease spread can be a valuable epidemiological tool. When responding to an epidemic, animal health personnel might be restricted to enacting existing policies that leave little scope for the trialing of new control strategies. Computational modelling compensates for the limited opportunities an epidemiologist has to experiment in the field.

Models of disease spread typically employ population-level approaches such as equation-based modelling, or individual-level approaches such as agent-based modelling. Population-level models can be concise and computationally efficient, but they do not isolate individual contributions to an epidemic. The finer granularity of individual-level models can introduce a computational overhead. In the case of a very large-scale model, an individual-level approach can require a highly parallel platform such as a high-performance computing cluster in order to function efficiently.

Epidemics are dynamically shaped by the complex interplay between host, pathogen and the environment. Modelling livestock disease spread on a national scale presents unique challenges due to large populations, varying herd types and farming practices, and regional and geopolitical differences. An alternative to pure population-level and individual-level modelling is a fusion of the two approaches into a hybrid model. This tactic is employed in the Australian Animal Disease Spread (*AADIS*) model, currently under development. The spread of disease within a herd is modelled from the top down by a system of ordinary differential equations. The spread of disease between herds is modelled from the bottom up by a spatially-aware agent-based model. Homogeneity is a reasonable abstraction for a herd of domestic animals and thus intra-herd spread of disease is well suited to equation-based modelling. The national set of herds is however, heterogeneous, making inter-herd spread of disease well suited to agent-based modelling.

AADIS models the transfer of disease from an infectious herd to a susceptible herd by five stochastic spread pathways: direct contact, indirect contact, local spread, airborne transmission and spread through saleyards. Herds can be viewed abstractly as autonomous nodes in a network. Over discrete time steps of one day, the disease spread pathways generate the network topology. Network paths can subsequently be traversed forward to assess the downstream impact of an infected herd, or backward to trace the historical infection route. The network topology thus captures the spatiotemporal history of the simulated epidemic.

AADIS is implemented in Java and employs open-source products such as PostgreSQL, PostGIS and OpenMap. It has an asynchronous object-oriented architecture that takes advantage of the inexpensive parallelism available on a multi-core x64 target.

Keywords: *AADIS, epidemiological model, hybrid model, spatiotemporal model, livestock disease spread.*

Probabilistic inference of disease outbreaks from a combined particle filter and Bayesian network analysis of electronic health record databases

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Abstract: Current electronic disease surveillance systems are not capable of exploiting the rich patient-level data within an electronic health record database. We present a methodology for using this data source based upon Bayesian network analysis of individual health records combined with a particle filter tracking the number of cases in the total population. Bayesian network methods have been used before in disease surveillance but the combinatorics involved with using them on a large scale population has limited their ability to track the number of cases.

The mathematical construct uses Bayesian network analysis of an individual's observables (symptoms, vaccinations history, etc), combined with prior knowledge of the health of the population, to provide a probability that an individual is ill, and with what disease. This is done for everyone in a population, employing the equivalence class methodology to group together people with identical observables to eliminate redundant calculations.

This information is then fed into a particle filter system which tracks probabilistically the continuous fraction of the population that is ill. This is made possible as both a particle filter and a dynamic Bayesian network can be used to describe a Markov Chain process, and through this it is shown that a particle filter can take the place of a dynamic node in a Bayesian network.

The current simplified prototype only tracks if an individual has gone to an emergency department (ED), and if so, whether they have respiratory symptoms. The system takes account of seasonal variability of respiratory conditions.

The system was tested against a simple simulation of bioterrorism attacks of pneumonic plague on a small population overlaid on freely available simulated emergency department triage data. The simulation deliberately does not include post-detection public health interventions. As can be seen in Figure 1, the system can detect outbreaks when the number of cases is difficult to distinguish from noise by eye. A systematic comparison of the probabilistic detection algorithm against ESSENCE (*Electronic Surveillance System for the Early Notification of Community-Based Epidemics*) Desktop Edition, a research edition of one of the most sophisticated currently deployed electronic disease surveillance systems, was performed. The test consisted of analysis of an ensemble of outbreaks. It was found that for low allowed false alarm rates, ≤1 per year, requiring high thresholds of detection, our system typically almost halved the detection time of ESSENCE. Across the whole spectrum our system outperformed ESSENCE, although the gains were small in the limit of a low threshold of detection and a corresponding large allowed false alarm rate.

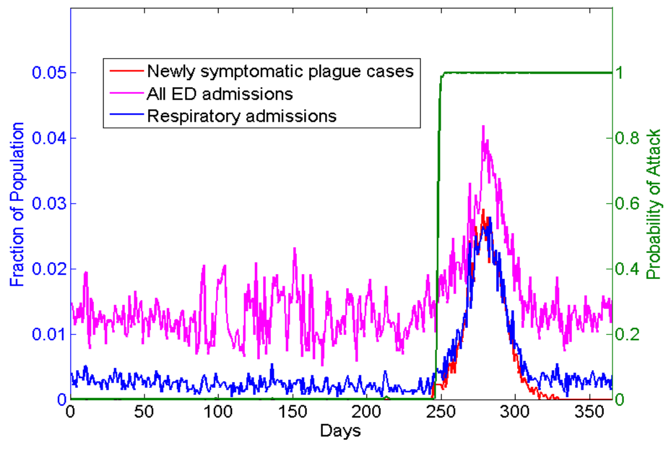

Figure 1. Probability of bioterrorism attack (green) against numbers of emergency department admissions (magenta), respiratory cases (blue), the number of newly symptomatic pneumonic plague cases (red).

Our framework is highly sensitive and delivers short detection times. It can outperform current systems, however unlike current systems has a heavy parameterisation burden. Future versions will make fuller use of health records for greater sensitivity and timeliness.

Keywords: *Surveillance, epidemics, Bayesian networks, particle filters, simulation*

Modelling symptom progression in individuals for disease surveillance

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Abstract: In order to create next generation disease surveillance systems for detecting biological attacks, which fully utilise patient records in an electronic health record, it is essential to be able to model how disease symptoms will appear in an attacked population with higher fidelity than has been done previously. In this paper detailed models of symptom progression of people infected with inhalational anthrax, pneumonic plague and influenza pneumonia are constructed. They are used within an agent based epidemic simulation to predict the prevalence of symptoms within the infected community over time. Influenza pneumonia was chosen as it is a common respiratory disease that presents with similar symptoms to inhalational anthrax and pneumonic plague.

The models were constructed through a combination of literature review and hospital record analysis, which advised on the nature of the symptoms of the diseases, the time lines of progression and the probabilities of progression, and using this information to construct mathematical models of how these diseases present in individuals (see Figure 1 for the influenza model). Due to imperfect knowledge of these diseases, due to lack of cases or constant mutation, most of the probability parameters associated with the models have an associated uncertainty range. In our models the middle values of these ranges have been chosen, however knowledge of the uncertainty ranges is retained for users of the models to sample from randomly, if required. The simplifying assumption that comorbidity with other diseases does not affect parameter values is made, when modelling individuals with multiple infections.

The disease progression is modelled as moving through a series of states, each with a lognormal probability distribution function describing duration, and with a range of possibilities for the next state. Each state has associated symptoms. As an approximation, all developed symptoms begin at the start of their associated state.

These models were then used in an agent based outbreak simulation of 1000 agents to model the prevalence of various symptoms, to illustrate their different appearance in a health record system. Ensemble results highlight that time dependent ratios of the prevalence of key symptoms are different between each disease. An anthrax attack, being non-contagious, produces a lognormal symptom onset curve, with fulminant stage symptoms time delayed. An influenza outbreak produces a longer epidemic with few cases with serious symptoms. A pneumonic plague attack produces a double peaked epidemic between primary cases and those that follow.

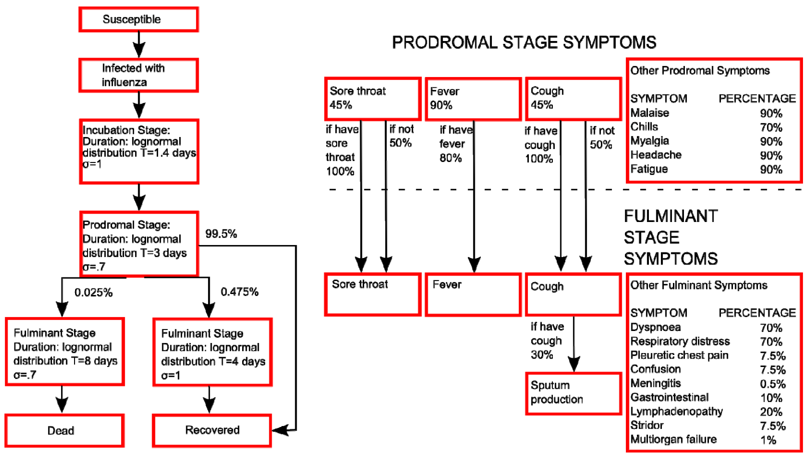

Figure 1. Diagrammatic representation of influenza model. Stage progression and timings to left, and symptom probabilities above. Symptoms developed continue until recovery or death.

These models are now being used to parameterise a dynamic Bayesian network based electronic disease surveillance system, which combines probabilistic analysis of medical records and outbreak timelines.

Keywords: *Epidemics, Bayesian networks, Simulation, Surveillance*

Empirical agent-based simulation of movement: the integration of high-frequency Flying-fox tracking data with a simulation model of population dynamics in time and space

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Abstract: Flying-foxes (bats) are of scientific interest and management concern globally due to the amenity, crop and disease threat they pose. A management priority in Australia is the threat of Hendra virus transmission from flying-foxes to horses, subsequently putting humans at risk from this deadly virus. Simulation models can improve our capacity to predict periods of high risk for Hendra virus transmission from flying-foxes to horses, by understanding both flying-fox and Hendra virus ecology and by modelling Hendra virus risk.

We are developing an agent-based model that couples the ecology of flying-foxes with Hendra virus transmission, in a spatial context (figure 1). An agent-based ecological approach is rarely used in modelling disease transmission and spread at the landscape scale. However, it is a powerful method for understanding this complex system, as flying-foxes are extraordinarily mobile and behave in an autonomous fashion. They also have a range of life-stages and behaviours that influence the timing and rate of virus spread, in particular individual bat 'condition'. We present a conceptual framework for our agent-based model, exploring the advantages of an agent-based approach in this context with wider implications for disease spread modelling of a range of organisms. Key questions that we will ask with our model are 1) *Where is the virus concentrated in the bat population*? i) who (which individual bats, e.g. stressed, young)? ii) when is the highest virus load during the year? iii) how does it spread with bat movement and dispersal? 2) *What does this mean for spill-over risk to horses?* This requires simulation of i) bat landscape use and ii) bat virus shedding.

We are developing this model in collaboration with novel field data utilizing state-of-the-art movement monitoring technology currently being deployed across the east coast of Australia (figure 2). Ultimately, we aim to use our combined knowledge from the field and from our agent-based model to aid decision making. We will i) develop, model and test relevant hypotheses for disease dynamics, ii) identify the drivers of disease outbreaks, and iii) identify and select effective management interventions. A good understanding of the spatial and temporal dynamics in flying-fox population distribution and structure will be crucial to the management of Hendra virus.

We present the development of the model to date, focusing on how we have integrated knowledge of bat movement gained from the analysis of tracking data with an ecological understanding of bat behaviour, to inform the simulation of bat movement and thus the projected pattern of virus shedding in time and space.

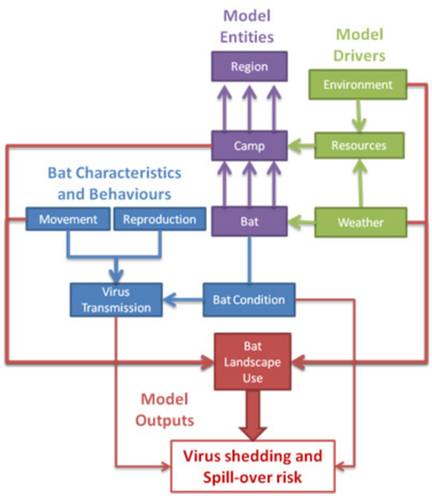

Figure 1: Agent-based model

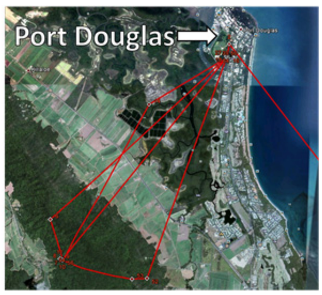

Figure 2: Movement monitoring: red line = individual bat movement pathway over a single night

Keywords: *Agent-based model, movement, disease ecology, Hendra virus, Flying-fox population model*

Modelling hepatitis C treatment strategies using empirically grounded contact network models

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Abstract: Hepatitis C virus (HCV) chronically infects nearly 200 million people worldwide, with over 350 000 estimated deaths attributed yearly to HCV-related liver diseases. It disproportionally affects people who inject drugs (PWID). Currently there is no preventative vaccine. Current medical treatments require long treatment durations (24 - 48 weeks), have severe side-effects, and are estimated to be effective in only about 60% of cases. Upcoming antiviral treatments will improve this situation. They will be more effective, have shorter treatment durations, and have less severe side-effects. These changes will make possible large-scale treatment interventions. How these strategies should target HCV-infected PWID remains an important unanswered question.

Previous models of HCV transmission have lacked empirically grounded contact models of PWID. Yet, it is increasingly recognised that contact networks are relevant to the transmission of diseases. Only recently has data been collected with network-based methods to allow contact network modelling of PWID. Even fewer studies have also included blood sample testing to determine current HCV infection status and prior HCV exposure. One such dataset has been collected in Melbourne, Australia. Using this data we have developed an empirically grounded contact network model of PWID and a model of HCV transmission on contact networks. Our network model is an exponential random graph model (ERGM), a family of models that is commonly used in social network analysis. ERGMs have proven to be effective in capturing network features and structures relevant to human interaction such as transitive closure, homophily and social circuit dependence. Since the Melbourne data was collected using network-based methods, recent results using conditional estimation of ERGM parameters were used to account for the data collection method. Our HCV transmission model is a detailed, stochastic, individual-based model including both nodes that are chronically infected, and nodes that spontaneously clear the virus (spontaneously clearing nodes; SCN) with the possibility of re-infection.

In this talk we report on results regarding HCV transmission and treatment from a simulation study combining our HCV transmission model with our data-driven contact network model for PWID. Regarding transmission we investigate the role of number of contacts and injecting frequency on time to primary infection, and the role of SCN on incidence rates of infection. Regarding treatment we investigate the effect of nine network-based treatment strategies on chronic prevalence and incidence rates of primary infection and re-infection. A key difference with other studies in network epidemiology is that a treatment, not a preventative vaccine, is considered. Necessarily, such treatments are administered only to infected people. We also assume such treatments provide no lasting immunity against re-infection. The nine strategies include choosing infected people at random, choosing infected people with the most contacts (analogous to *targeted vaccination*), and choosing a PWID and treating all their infected contacts too (analogous to *ring vaccination*).

In the context of transmission, we find both larger numbers of contacts and higher injecting frequency are associated with reducing time to primary infection. The change from “less-” to “more-frequent” injector is roughly the same as having one additional network contact. For a fixed number of SCN spread randomly through the network, we find their locations do not have a statistically significant effect on the network-wide incidence rate of combined infection (i.e., primary + re-infection).

In the context of treatment, re-infection plays a large role in the effectiveness of treatment interventions. Network-based strategies that choose PWID and treat all their contacts were most effective in reducing both the incidence rates of re-infection and combined infection. A strategy targeting infected PWID with the most contacts was the least effective.

Keywords: *Social networks, epidemiology, simulation, individual-based.*

Estimating influenza incidence across time, space and population age from routinely collected surveillance data

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Abstract: The influenza virus is transmitted in three dimensions across space and time and depends in complex ways upon the features of its hosts and the hosts' environment. In urban human populations, variation in spatio-temporal patterns of transmission stems from multiple factors including population density and regional demographics, social networks influencing contact patterns and socioeconomic factors influencing health and healthcare access. Spatio-temporal mathematical models of influenza transmission can be used to probe the mechanisms of epidemic growth and assess the potential effects of population-level interventions, both of which may depend in subtle ways on these multidimensional factors. Our capacity to validate these models, however, is limited by the availability of high-quality multidimensional data.

Influenza surveillance systems enable systematic collection of influenza-related data that are used to detect influenza outbreaks, monitor circulating strains, inform pandemic responses, assess the effectiveness of interventions and conduct epidemiological research. In Victoria, laboratory-confirmed influenza cases are notifiable by law to the Victorian Department of Health (VDH). The Victorian Infectious Diseases Reference Laboratory (VIDRL) co-ordinates two additional influenza surveillance systems. The General Practice Sentinel Surveillance Scheme (GPSS) involves passive reporting of influenza-like illness (ILI) presentations by volunteer general practices, a subset of which are swabbed and laboratory-tested by VIDRL. Reports of ILI cases presenting to the Melbourne Medical Deputising Service (MMDS), an after-hours locum medical service, are also collated by VIDRL.

The data collected by these surveillance schemes capture a biased, noisy subset of the underlying influenza epidemic. Noise stems from low specificity in the method of case ascertainment, leading to false positives- a particular problem for ILI-based surveillance. Conversely, laboratory testing yields higher (although variable) specificity, but often low sensitivity due to limited testing rates. Temporal, spatial or demographic bias may occur due to, for example, bias in presenting behaviour by age, or geographical bias in case reporting due to the spatial distribution of notifying clinics. Although bias and noise present problems for the interpretation of these surveillance data, each system can be seen as capturing a different aspect of the true epidemic. Meta-analysis of these datasets can hence yield deeper insights into the underlying influenza epidemic.

In this study we employ data from the VDH, GPSS and MMDS influenza surveillance systems in Melbourne, Victoria. Each dataset contains records of influenza (or ILI) cases referenced by time, location and patient age across three influenza seasons (2009-2012), for a total of 21,271 data points. We first discuss the reporting process for the VDH, GPSS and MMDS surveillance systems and describe the distribution of influenza cases captured by each. The results are used to assess sources of bias in the datasets. This analysis informs the use of multiparameter Bayesian evidence synthesis to estimate the distribution of incident influenza cases across four dimensions: 2-dimensional space, time, and population age. Finally, we discuss how these results can be used to fit spatio-dynamic, age-specific models of influenza spread and outline applications of such models.

Keywords: *Influenza surveillance, Bayesian evidence synthesis, infectious disease modelling*

Modelling Submarine Groundwater Discharge (SGD) in the Estuary Using Radon and Salinity Measurements

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Abstract: Submarine groundwater discharge (SGD) is regarded as an important pathway to transport dissolved substances to estuaries and coastal embayments. However, due to its spatial and temporal variations, SGD is difficult to measure making its contribution towards coastal nutrient budgets uncertain. Natural tracers such as the radon isotope ^{222}Rn are orders of magnitude higher in groundwater than surface water and may be used to overcome this difficulty. Radon losses due to radioactive decay and to gas exchange. There are no biochemical sinks for radon as they are chemically inert and electrically uncharged. Radon behaves conservatively spanning the salinity range from freshwater to seawater. The ultimate fate of radon is degradation through radioactive decay, with a relatively short half-life ($t_{1/2}$=3.8d), and therefore any detection in surface waters indicating SGD is active. Despite the advances that have been made in using Radon to characterise SGD, scaling up measurements, made at a relatively fine-scale, is difficult due to inherent spatio-temporal variability, morphological and hydrological dynamics.

This study applies an inverse technique that utilises Radon ^{222}Rn data and a 3-D hydrodynamic and isotope-enabled model to unravelling the contribution of SGD in the nutrient budget of the Caboolture Estuary, Queensland. Five 25 km-long spatial surveys, ten time-series measurements of ^{222}Rn at one station in the estuary and in two tributaries, along with the measurements in groundwater bores (up to 1.5m depth) are utilised. The sampling campaign covered a period from Dec 2011 to Nov 2012. Radon ^{222}Rn concentration measured in the groundwater is in the order of magnitude of 10^2 to 10^3 Bq/m^3, compared to the estuary of 10^{-2} to 10^2 Bq/m^3 and tributaries of 10^1 Bq/m^3.

As a first-step, a 1-D framework is constructed to reproduce the behaviour of a 3-D hydrodynamic model for locations at which calibration data were measured. The calibration provides an efficient test-bed environment in which model parameters are estimated using a Bayesian calibration framework - Markov Chain Monte Carlo (MCMC). Next, spatial SGD zones are added in the model; the zones boundaries are determined from topography and groundwater contour map. Mean posterior parameters derived from MCMC framework are then ported into the 3-D hydrodynamic-radon model of Caboolture Estuary. The fluxes from the SGD zones are derived by optimising the solution of the 3-D model to match along-stream profiles of water column radon, salinity and temperature. The spatial and temporal uncertainty of model predictions due to parameter estimation and observation error is quantified.

Keywords: *Bayesian, hydrodynamic, modelling, radon, uncertainty*

Surrogate groundwater models

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Abstract:

Numerical groundwater models are often employed to produce outputs varying over a large geographical area and over an extended period of time. Uncertainty analysis is critical due to a paucity of data and knowledge about subterranean environments. However the required complexity makes uncertainty analysis computationally intractable. Surrogate modelling aims to provide a simpler, and hence faster, model which emulates the output of a more complex model. We summarise surrogate modelling techniques in three categories: data driven, projection, and physically based approaches.

Data driven approaches discussed include artificial neural networks, support vector machines, dominant mode analysis, Guassian processes, radial basis functions, and Bayesian networks. A number of weaknesses of such methods are discussed, most notably the difficulty in dealing with a large number of spatially distributed parameters.

Projection based approaches involve projecting the governing equation onto a reduced dimensional subspace. Beyond the traditional SVD and Krylov based methods, we investigate approaches which aim to provide a bound on the error due to the surrogate model.

The most promising physically based approaches, namely multi-scale finite element methods, are yet to be widely applied to groundwater problems.

Although other reasons for using surrogates are discussed, we note that reducing model runtime is the major motivation for building a surrogate model. With this in mind, we argue that computational techniques provide an alternative without the potential losses in accuracy and costly implementation. It is found that parallelism, or using different software, can readily achieve speedups comparable to those of many surrogates.

In the discussion the application of surrogate techniques to groundwater modelling, we note several imbalances in the existing literature; a large body of work on data driven approaches seemingly ignores major drawbacks to the methods; only a fraction of the literature focusses on reproducing fully distributed groundwater models, despite these being ubiquitous in practice; and a number of the most sophisticated surrogate modelling methods are yet to be fully applied in a groundwater modelling context.

Keywords: Surrogate model, meta model, reduced order model, groundwater

Physical Statistics or Statistical Physics? A Brief Overview of Bayesian Melding

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Abstract: For scientists, a model is typically a set of mathematical formulae that describe some natural phenomena of interest. One approach, often preferred by applied mathematicians, engineers, and physicists, is to discover physical laws of nature and express them as deterministic mathematical relationships among quantities that comprise such laws. At the opposite end of the spectrum, physical laws that gave rise to the data may be of little concern to students in an undergraduate statistics course, whose emphasis is on discovering empirical relationships among observable quantities and construct regression models that relate both observable and unobservable quantities, including random noise. Practising statisticians express known physical laws in their regression models; what makes a regression model *empirical* is that the behaviour of deviations (noise) from the mathematical formulae is an integral part of the model itself. For years, Bayesian hierarchical modelling has been the statistical framework of choice to integrate empirical and deterministic modelling. Bayesian melding is a more recent alternative statistical framework: it expresses physical laws as laws, thus without explicit noise terms, yet it still allows the focus to be placed on the behaviour of random quantities. In this overview, we discuss some philosophical underpinnings of the Bayesian melding approach, and through a toy example we illustrate the nuances of formulating a Bayesian melding model. We list some published and ongoing research in ecology, economics, engineering, epidemiology, and population dynamics that employ Bayesian melding; these examples suggest the potential for Bayesian melding to unify deterministic and statistical modelling approaches in general.

Keywords: *Bayesian melding, computer models, deterministic models, empirical models, hierarchical models, mathematical models, process models, simulation models, state-space models, statistical inference*

Using Bayesian hierarchical models to measure and predict the effectiveness of environmental flows for ecological responses

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Abstract: Quantitative predictions of ecological responses to flow alterations are fundamental to the planning and delivery of environmental water. However, the majority of such predictions are often based on expert opinion, and lack a solid basis in empirical evidence. To derive evidence-based, defensible environmental flow recommendations, new approaches are required that make best use of the available data to predict ecological responses to flow alterations. In this study we use Bayesian hierarchical modelling to explore the impact of changed flow regime on terrestrial vegetation encroachment into river channels. In regulated rivers, encroachment of terrestrial vegetation into the channel is an issue of concern for managers because duration, frequency, and season of inundation are major determinants of plant community development. Environmental flows are often recommended as a way of reducing encroachment, but the assumed response has not been rigorously tested. Neither are there any general quantitative models that describe the predicted benefit (in terms of reduced terrestrial vegetation encroachment) of different flow regimes. In this paper we report a Bayesian approach that identifies the relationship between flow and vegetation encroachment revealed in seven integrated data sets from south eastern Australia. A principal advantage of Bayesian modelling is its flexibility. Thus, one is able to model physical and biological processes as part of a hierarchical statistical analysis. Here, we describe the relationship between terrestrial cover and inundation using a curvilinear function that combines both inundation duration and the number of inundation events. The model also incorporates hydrological data for the 5 years prior to vegetation sampling, weighting the most recent years most heavily. Finally, it accounts for effects of bank slope, season of inundation, and random effects associated with sampling (year of sampling, sampling transect, and uncertainty associated with the survey technique used). The model also improves the precision of estimates by using expert-derived prior probability distributions for model parameters, and by having a hierarchical structure among sites and rivers. Bayesian hierarchical models assume dependency amongst the sampling units, and therefore the model parameter values are assumed to be drawn from a larger common distribution. Relationships from each site 'borrow strength' from other sites, leading to robust influence despite the common problems associated with sample replication in environmental monitoring studies such as this. By combining data across seven different river systems, we are able to quantify relationships between different inundation durations and frequencies and the extent of terrestrial vegetation encroachment. This, in turn, allows us to make predictions of encroachment under different flow regimes. The hierarchical nature of the model allows us to report at the site and river level and also at the state level. These are the scales of interest to local stakeholders and the state funding agencies. Our results highlight the power and flexibility of Bayesian models to make quantitative, evidence-based predictions of ecological responses to changes in flow regimes. Such models will be vital for the future of environmental water management in data-poor situations that are common to environmental monitoring, and produce outcomes that are reportable at different stakeholder and governance levels.

Keywords: *Bayesian hierarchical model, environmental flows, terrestrial vegetation encroachment*

RoseDist: Generalized Tool for Simulating with Non-Standard Probability Distributions

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Abstract: Monte Carlo simulation is the most popular technique for performing uncertainty quantification for being easy to implement and requiring very few assumption on the behavior of the model. However, in cases where model evaluations are computational costly, the technique can be become too expensive since Monte Carlo requires a high number of evaluations to get reasonable accuracy. To mitigate this cost, various variance reduction techniques have been introduced to increase the convergence rate. Unfortunately these techniques are only just making in-roads into computational modelling because of their inherent complexity and interdependence. `RoseDist` is a software toolbox in `Python` designed to make most variance reduction technique accessible, in an object-oriented sense, to numerical modellers from various disciplines.

Keywords: *Monte Carlo simulation, Quasi-Monte Carlo, Rosenblatt transformations, Copulas, Variance re-duction, Custom constructor*

Practical state-space modelling with LibBi

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Abstract:

The development of mechanistic models to describe physical, chemical and biological phenomena is a common activity across a range of scientific disciplines. There is considerable interest in drawing on such models for statistical inference, particularly in a Bayesian setting, where they might be incorporated as informative prior knowledge. The state-space model (SSM) is a versatile framework for this. SSMs are a special case of the broader class of Bayesian hierarchical models (BHMs). They consist of parameter, state and observed variables, over which a joint probability distribution is specified by writing down parameter, initial state, transition and observation models, each a (conditional) probability distribution. Where a mechanistic model is available, this enters into the specification of the transition model.

Inference consists of conditioning this joint distribution on particular instantiations of the observed variables, taken from an observational data set, to arrive at the posterior distribution. The computational method chosen to perform this inference procedure is critical, as it will not necessary admit the specified SSM, in which case compromises will need to be made to the preferred form. For example, the Kalman filter requires a linear and Gaussian transition model, and the Gibbs sampler requires at least that the transition model has a closed-form probability density function. More recent techniques based on sequential Monte Carlo (SMC), or the particle filter, impose fewer constraints, typically only requiring that the transition model can be simulated forward in time, so that nonlinear and non-Gaussian models are readily admitted. Extensions such as particle Markov chain Monte Carlo (PMCMC) and SMC^2 exhibit the same quality. A further advantage of SMC-based methods is that they are particularly amenable to parallelisation on modern high-performance computing machines, which may be advantagous for particularly complex mechanistic models.

This work introduces state-space modelling and SMC-based methods via the software package LibBi (*www.libbi.org*). LibBi features its own modelling language, in which an SSM can be easily specified via its parameter, initial state, transition and observation models. SMC-based inference routines may then be run on the model, with an appropriate data set, to produce posterior samples. The software is demonstrated on a number of case studies in marine and soil biogeochemistry.

Keywords: Physical-statistical modelling, state-space modelling, Bayesian hierarchical modelling, particle filter, sequential Monte Carlo, particle Markov chain Monte Carlo, high performance computing

Incorporating a generalised additive model of river nutrient concentrations into a mechanistic receiving water model

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Abstract: eReefs is a large, collaborative project that is building catchment and marine models for Australia's Great Barrier Reef Lagoon (GBRL), a world-heritage environmental asset. The eReefs package includes three-dimensional mechanistic biogeochemical, sediment and hydrodynamic models for the entire GBRL on 4 km and 1 km grid scales, along with a relocatable coastal and estuary model (RECOM) that can be nested within the larger-scale models. Source Catchment models developed by the Government of Queensland for each GBRL catchment will be used to run scenarios to predict the effects of management and land use changes on nitrogen, phosphorus and sediment loads reaching each river. For day-to-day near-real-time and forecast-mode running of the marine models, however, another approach is needed to provide the river loads of sediments, dissolved and particulate loads required as boundary conditions.

Generalised Additive Models (GAMs) have been shown (e.g. Kuhnert et al., 2012) to be powerful tools for the prediction of suspended sediment and particulate nutrient loads in tropical rivers. Here, we extend previous work to build GAMs that are able to predict concentrations of suspended sediments, dissolved and particulate nutrients in the Fitzroy River (Queensland) on a daily time-step.

In developing the GAMs, we tested a number of routinely and frequently measured meteorological and hydrological variables for potential predictive power. The new terms considered included water temperature (which may alter biogeochemical processing rates), air temperature (a more reliably measured proxy for water temperature), electrical conductivity (which may reflect the influence of particular subcatchment sources), barometric pressure (an indicator of local storm activity), wind stress (which may affect resuspension and mixing in the river and its weirs) and flow from river tributaries (a direct measure of the influence of particular subcatchments). The models generated were tested with regard to the validity of key statistical assumptions, and were then validated against a subset of observational data that had been held back from the original calibration.

The strongest models included flow in the Fitzroy River, flow in one or more tributaries, and a discounted flow term that reflected flow in the preceding days and weeks. Models that did not include tributary flow were able to predict concentrations of particulate, but not dissolved materials. Neither meteorological terms nor electrical conductivity proved to be useful predictors, while water temperature was of marginal value.

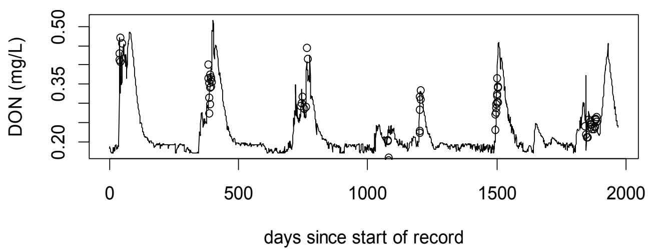

Figure 1 Time-series of dissolved organic nitrogen (DON) from the GAM for input to marine models. Observations are shown as dots.

The final GAM provide more accurate predictions on a daily time-step than previously available methods, for both dissolved and particulate materials, and is being used to provide time-series input (e.g. Figure 1) to mechanistic marine models.

Keywords: *eReefs, dissolved nitrogen, dissolved phosphorus, statistical model, nutrient loads, sediment loads*

Grappling with time-scales - linking land use and stream ecosystem health

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Abstract: Recent policy changes in New Zealand require regional councils to set limits on water quality in waterways and to manage land use to meet those limits. Nitrogen (N) and phosphorus (P) losses from farm land cause problems in many waterways – notably excessive biomass of periphyton (attached aquatic plants) in shallow, cobble-bed rivers during summer low flows. Currently the preferred tool for estimating N and P losses from farmland in NZ is the OVERSEER model - an equilibrium paddock-scale nutrient budget model developed by AgResearch to help optimize farm production. OVERSEER estimates annual average N and P losses, and although not its original objective, is being used to assess the impacts of farming on water quality. One modelling challenge is that periphyton biomass varies on time scales of days-weeks because floods exceeding 1-3x median flow 'reset' biomass through scour. The rate of biomass accrual after a flood depends on N and P concentrations, which depend on losses from farmland. A second challenge is that N and P concentrations vary in space and time as a result of uptake and recycling within the stream channel (nutrient spiraling). Quantifying the relationship between annual N and P losses from land and summer low flow periphyton biomass poses significant modelling challenges.

The Tukituki River, Hawke's Bay, is a shallow, cobble-bed river with a history of summer low flows and 'nuisance' periphyton biomass. Irrigation and land use intensification are proposed and a conceptual model TRIM has been developed to assess the likely impacts. TRIM_CATCHMENT uses OVERSEER to estimate annual N and P losses and results from a MODFLOW groundwater model to route N through groundwater and to estimate annual N and P inputs into each 600m reach of the network of streams 4th-order and larger. Attenuation is 'calibrated' by matching observed and predicted annual yields at c. 10 monitoring sites. TRIM_STREAM generates synthetic daily inputs of water, N and P into each stream reach. A statistical sub-model is used based on the relationships between nutrient concentration, flow and time at the monitoring sites. TRIM_STREAM then uses a deterministic model to predict the spatial and temporal variations of nutrient concentration and periphyton biomass.

The sensitivity of TRIM_CATCHMENT to uncertainties in input data and calibrated attenuation coefficients has been assessed and it provides fairly robust predictions about the impacts of intensification on N and P losses and stream inputs. The TRIM_STREAM model is somewhat more speculative because of uncertainty about aspects of nutrient delivery, recycling and loss. However, it is doubtful whether a more complex physically-based model would be any more successful in the face of this uncertainty.

Keywords: *Nitrogen, phosphorus, periphyton, irrigation, modelling*

Probabilistic Ecosystem Model for Predicting the Nutrient Concentrations in the Gulf of Finland

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Abstract: Many countries define legislative targets for the ecological status of aquatic ecosystems. Fulfilling these legally binding targets requires often large scale and expensive management actions. The expected benefits from alternative actions are commonly compared with deterministic ecosystem models. However, from a practical management point of view the uncertainty in model predictions and the probability to achieve the targets are as essential as the point estimates provided by the deterministic models. For this reason, we extend a deterministic ecosystem model into a probabilistic form. We use the model for predicting the probability to achieve the targets set by European Union's Water Framework Directive (WFD) in Finnish coastal waters in the Gulf of Finland (GoF), one of the most eutrophicated areas of the Baltic Sea, under alternative management scenarios. The deterministic ecosystem model is a 3-dimensional hydrodynamic-biogeochemical model with a simple nutrient cycle (inorganic nutrients) and two phytoplankton groups. The model uses spatial resolution of 5 km for an area of size, approximately, 600kmx150km. The vertical dimension of the model is divided into 17 layers that are 2 m thick until the depth of 20 m and stretched to 5m, 10m, and 50m thick layers after that. The deterministic ecosystem model is first calibrated for years 2000-2004 by using dissolved inorganic Nitrogen (DIN), dissolved inorganic Phosphorus (DIP), and chlorophyll-a measurements from two intensive monitoring stations from the Finnish coast of the GoF. After this we combine the deterministic spatio-temporal predictions with a Gaussian process to give a prior distribution for the spatio-temporal function of nutrient concentrations with various loading scenarios. We use Bayes theorem and condition to large monitoring data set from 2000-2004 to calculate the posterior predictive distribution of the nutrient concentrations. Our approach treats the parameters of the deterministic ecosystem model as known and fixed to the point values determined by the manual calibration but accounts for the uncertainty in the model prediction through the model inadequacy, residual variation and observation error. We present results on model inadequacy analysis and predictions for three different management scenarios. This presentation will summarize the following work: Vanhatalo et al. (2013). Probabilistic Ecosystem Model for Predicting the Nutrient Concentrations in the Gulf of Finland under Diverse Management Actions. Environmental Science & Technology, 47(1):334-341

Keywords: *Ecosystem model, Uncertainty analysis, Gaussian process*

Filling gaps in daily rainfall data: a statistical approach

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Abstract: Daily rainfall data are one of the basic inputs in hydrological and ecological modeling and in assessing water quality. However, most data series are too short to perform reliable and meaningful analyses and possess significant number of missing records. The study focuses on developing a methodology to fill the gaps in daily rainfall series considering data of twenty rainfall stations from Brahmani Basin, Rachi, India. A probabilistic approach is adopted to generate data for filling on missing points.

The Poisson-gamma (PG) distributions were explored in the study as they possess useful properties to simultaneously model both the continuous (rainfall depth) and discrete (rainfall occurrence) components of daily rainfall. First, the PG distributions were fitted to the daily rainfall data of targeted stations and the parameters were estimated. The models were compared with the widely used inverse distance interpolation method. To compare the fit of the models, a dataset of size equal to the size of the observed dataset were generated. The means and percentages of days with no rainfall of observed and simulated datasets were very similar. However, PG distributions slightly overestimate the 95th percentile and underestimate the variance and 99th percentile. This indicates that the models do not capture well the extremely heavy rainfall events; hence, the PG distributions need to modify to capture better the extreme events. However, with respect to all statistics, the PG model performs better than the inverse distance interpolation method.

The methodology considers two basic assumptions.

- The rainfall data of missing period have similar statistical properties to the data from available periods. Fairly large amounts of data exist to generalize the parameters from the available periods to the points with no data. The assumption is also supported by the fact that, for the studied stations, the first and second halves of the available datasets possess similar statistical properties.
- Spatial correlations exist among rainfall occurrence and amounts of neighboring stations. The fact is reasonable as fairly negative relationship were observed between correlation of daily rainfall and distances among the studied stations.

Once the PG distributions were decided, samples were generated with the parameters of respective stations. The generated data for a station is completely random in nature and independent of the rainfall amounts of neighboring stations. To match the data, first the rainfall amount of the region is estimated as the weighted mean of rainfall amounts from four closest stations. Weights were taken as the inverse of the distances of the neighboring stations from the target station. Days were sorted from driest to wettest on the basis of the mean rainfall amounts of neighboring stations, and finally, the generated data were matched.

Instead of using two separate models for generating continuous data (rainfall depth) with exact zero (no rainfall), the proposed method use a single model to model both components of daily rainfall simultaneously. The method resolves the problem of overestimating non-zero rainfall amount that arises while using traditional interpolation methods. However, the method may not work well when the neighboring stations are not close to the target station.

Keywords: *Daily rainfall, Poisson Gamma (PG) distribution, interpolation*

Are Spatial Modelling Methods Sensitive to Spatial Reference Systems for Predicting Marine Environmental Variables?

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Abstract: Spatially continuous information is often required for environmental planning and conservation. Spatial modelling methods (SMMs) are essential for generating such information from point data. The accuracy of spatial predictions is crucial for evidence-based decision making but is potentially affected by many factors. For example, spatial reference systems may alter the features of spatial data and thus are likely to affect predictions from SMMs. However, the degree to which such systems can affect spatial predictions has not been examined. It is also not clear whether different types of SMMs respond differently to the choice of a spatial reference system.

In this study, we aim to test how sensitive SMMs are to different spatial reference systems. On the basis of a review of spatial reference systems, we selected eight systems that are suitable for spatial predictions of marine environmental variables in the continental Australian Exclusive Economic Zone (AEEZ). These systems include two geographic coordinate systems (WGS84 and GDA94) and six map projections (Lambert Equal-Area Azimuthal, Equidistant Azimuthal, Stereographic Conformal Azimuthal, Albers Equal-Area Conic, Equidistant Conic and Lambert Conformal Conic). Two most commonly used spatial interpolation methods, i.e. inverse distance squared (IDS) and ordinary kriging (OK), were applied to a seabed sediment dataset that was projected using the eight systems. The accuracies of the methods were assessed using leave-one-out cross validation in terms of their predictive errors (mean absolute error and relative mean absolute error). The spatial prediction maps were also generated and visualised for comparison. The differences in the predictive errors resulted from WGS84 and the map projections were compared using paired Mann-Whitney test for both IDS and OK. The data manipulation and modelling work were implemented in ArcGIS and R.

Results from this study show that whether the data is projected on spherical surfaces based on the geographic coordinate systems or on planar surfaces based on the map projections, the accuracies of the SMMs (IDS and OK) in predicting seabed sediment data in the southwest region of AEEZ are similar and the differences are considered negligible, in terms of both predictive errors and prediction map visualisations. Thus, it is concluded that the SMMs examined are not sensitive to the spatial reference systems tested for spatial predictions of seabed sediment data in the southwest region of AEEZ. However, a few factors may potentially alter the degree to which spatial reference systems affect spatial predictions, e.g. search window size, data density, data spatial distribution and dataset location. Hence further work is required to test different datasets located in other regions and to test a variable search window size.

The outcomes of this study have significant implications for spatial predictions in environmental science. The results suggest that spatial predictions using datasets with a density comparable to or greater than that in this study may use WGS84 directly and may not have to project data on a certain spatial reference system. This would greatly increase data processing efficiency. The findings are applicable to spatial predictions of both marine and terrestrial environmental variables.

Keywords: *Spatial reference systems, inverse distance squared (IDS), ordinary kriging (OK), geostatistics, Australian Exclusive Economic Zone (AEEZ)*

Improved Sea Surface Temperature/Rainfall Forecasts by Multi-model Combination approach

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Abstract: Seasonal climate predictions are in high demand in Australia; particularly seasonal rainfall forecasts are sought by irrigators, water managers and others throughout the year. Rainfall potential at regional to continental scales is altered by the seasonal to interannual climatic variations resulting from changing sea surface temperature (SST) conditions. Predicting these climatic variations in advance provides useful information to planners and operational agencies toward developing contingency measures and strategies to cope with the adverse effects of extreme events. In this study a Bayesian Model Averaging (BMA) method is implemented for formulating seasonal rainfall forecasts over Australia using climate indices based on SSTA as predictors.

Monthly SST forecasts from five available GCMs (ECMWF, CCMC, IFM, Meteo-France, UK Met Office) of the ENSEMBLES project along with the POAMA are used to develop a combined multi-model SST forecasts for the four seasons (February-April, May-July, August-October, and November-January) for the time period 1980-2005. As the multi-model combination approach used to obtain SST forecast takes into accounts the correlations among the models, it is found to offer consistent and significant improvements in SSTA forecast at majority of grid points around the globe rather than using a single model. It is hoped that these improved SSTA forecasts (or derived climate indices) will lead to improved seasonal rainfall forecasts over Australia.

Keywords: *Sea surface temperature, CGCM, 'K' nearest neighbour, Bayesian Model Averaging*

Predicting the spatial distribution of seabed gravel content using random forest, spatial interpolation methods and their hybrid methods

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Abstract: Spatially continuous information of seabed sediments is often required for a variety of activities including seabed mapping and characterisation, prediction of marine biodiversity, and marine environmental planning and conservation. As seabed sediment data is often collected by point sampling, spatially continuous information must then be predicted from the point data. The accuracy of the predicted information is crucial to evidence-based decision making in marine environmental management and conservation. Improving predictive accuracy by identifying the most accurate methods is essential, but also challenging, since the accuracy is often data specific and affected by many factors.

Because of the high predictive accuracy of machine learning methods, especially Random Forest (RF), they were introduced into spatial statistics by combining them with existing spatial interpolation methods (SIMs), which resulted in new hybrid methods with improved accuracy. This development opened an alternative source of methods for spatial prediction. These hybrid methods, especially the hybrids of RF with inverse distance weighting (IDW) or ordinary kriging (OK) (i.e. RFOK or RFIDW), showed their high predictive capacity. However, their applications to spatial predictions of environmental variables are still uncommon. Model selection for RF and the hybrid methods is necessary and further test is required. Furthermore, model averaging has been argued to be able to improve predictive accuracy, but no consistent findings were observed in previous studies.

In this study, we aim to identify the most accurate methods for spatial prediction of seabed gravel content in the northwest Australian Exclusive Economic Zone. We experimentally examined: 1) whether input secondary variables affect the performance of RFOK and RFIDW; 2) whether the performances of RF, SIMs and their hybrid methods are data specific; and 3) whether model averaging improves predictive accuracy of these methods. For RF and the hybrid methods, up to 21 variables were used as predictors. The predictive accuracy was assessed in terms of relative mean absolute error and relative root mean squared error based on the average of 100 iterations of 10-fold cross-validation.

The findings of this study are:
- the predictive errors fluctuate with the input secondary variables;
- the existence of correlated variables can alter the results of model selection, leading to different models;
- the set of initial input variables affects the model selected;
- the most accurate model may be missed during the model selection;
- RF, RFOK and RFIDW proved to be the most accurate methods in this study, with RFOK preferred;
- these methods are not data specific, but their models are, so best model needs to be identified; and
- Model averaging is clearly data specific.

In conclusion, model selection is essential for RF and the hybrid methods. The best model needs to be identified for individual studies and application of model averaging should also be examined accordingly. RF and the hybrid methods have displayed substantial potential for predicting environmental properties and are recommended for further testing for spatial predictions in environmental sciences and other relevant disciplines. This study provides suggestions and guidelines for improving the spatial predictions of biophysical variables in both marine and terrestrial environments.

Keywords: *geostatistics, machine learning, spatial modelling, random forest, spatial interpolation*

Levy stable distribution to model stochastic processes in GNSS time series

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Abstract: When extracting geophysical information from GNSS time series such as co-seismic offset displacements or sites velocity, the estimates are biased due to the stochastic properties of the noise. It is then essential to model the noise in an accurate way. It is well-known that the noise in GNSS coordinate time series follows a power-law noise model with different components (white noise, flicker noise, random-walk). Several studies explain the relationship between the spectral index of the power-law noise and the Hurst parameter, and the use of the fractional Brownian model to classify the noise in three categories: persistent (long memory effect), anti-persistent (fractional Gaussian noise) or pure random walk. Here, we propose to model the coloured noise in the geodetic time series using the relationship between the Hurst parameter and the Levy exponent (e.g. Levy process). We can then compare statistically the difference with using a Gaussian distribution with a colored noise variance and the Levy stable distribution. This aims at new ways to study the stochastic properties of the GNSS time series and detecting outliers.

The application of Global Navigation Satellite System (GNSS) observations for monitoring geophysical phenomena such as earthquakes and tectonic movements requires also understanding the long term coordinate time series error spectrum. This work investigates different statistical distribution to best fit the noise contained within GNSS station coordinate time series. The general method used is to fit and remove a linear trend to the coordinate time series and then model the noise characteristics of the residuals. It is crucial to know the statistics of the different noise components for applications such as checking the significance of estimated earthquake co-seismic offsets and/or tectonic velocities from noisy GNSS time series. Several studies have shown that the error spectrum of geodetic GNSS time series is best characterised by a stochastic process following a power-law as:

$$S(f) \cong 1/f^{\alpha}$$

with the power spectrum (S(f)), and α the spectral index. Following this model, researchers demonstrated that the noise is coloured with mainly three components: white noise, flicker noise and random walk. White noise is independent of frequency, and is generally associated with hardware noise or measurement errors. Good knowledge of the noise statistics would help to exclude rather noisy GNSS time series when processing measurements from a global network of stations to estimate geophysical parameters such as the co-seismic offsets associated with earthquakes, and offsets arising from instrument upgrades and changes. Besides, it can also enable efficient filtering (e.g. Kalman filter applied to filtering outliers in GNSS time series). A power-law noise model means that S(f) is not flat but is governed by long-range dependencies. If the probability density function of the noise is Gaussian or has a different density function with a finite value of variance, its fractal properties can be described by the Hurst parameter (H). In 1968, B. Mandelbrodt defined the fractional Brownian motion (fBm) model using H. In the case of H < 0.5, the process behaves as a Gaussian variable; if H > 0.5 the process exhibits long-range dependence; while the case of H = 0.5 corresponds to a pure Brownian motion (white noise). However, H is directly connected with α by the relation: $\alpha = 2H - 1, \alpha \leq 2$

With this definition, flicker noise corresponds to α = 1 or H = 1, and white noise is related to α = 0 (H = 0.5). It is, however, difficult to look directly into the GNSS time series to characterize the various fractal properties because the different noise components are correlated. One way to model such stochastic processes is to use heavy-tailed distributions ($P[X > p] \sim p^{l}, p \to \infty, 0 < l < 2$) such as the levy stable distributions. Levy stable distributions are fractal, with a parameter (levy index) linked directly to the Hurst parameter as $l = 1/H$. In other words, l measures the fractal dimension of the probability space. One could then use ARMA (Autoregressive moving average) and F-ARMA methods to detect outliers in GNSS time series.

Keywords: *GNSS time series, coloured noise, outliers, Hurst parameter, Levy stable distribution*

EXTENDED ABSTRACT ONLY

Application of Kriging to groundwater level interpolation

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Abstract: Groundwater is a vital water resource for Australia and in many regional and rural areas is the primary source of water supply. It is estimated that groundwater is the source of approximately 30 per cent of total water use in Australia. Under the Commonwealth Water Act 2007, the Bureau of Meteorology is tasked with a range of functions including the requirements to collect, house and make available water data and to analyse these data to provide water information products for the nation. The Bureau is using groundwater data to assess the groundwater resource status, the regional water balance and trends in groundwater levels for the National Water Account and Australian Water Resource Assessment report.

Watertable elevation is a key component of describing the groundwater resource in unconfined aquifers. To describe the resource, groundwater levels observed in bores need to be interpolated to estimate a continuous watertable surface for large regional areas. The Bureau of Meteorology is applying an interpolation method developed by Melbourne University that uses Kriging with External Drift – KED (this work was undertaken in an ARC Linkage Grant).

The method combines a multi-variate version of KED with the Digital Elevation Model (DEM) as a physical constraint to groundwater head. The KED facilitates inclusion of continuous variables that are linearly correlated with head (for example land surface elevation) and is used to produce a watertable surface that results from these variables alone.

This paper presents the application of this KED method to model water table elevations and demonstrates the improvements gained - it is especially effective in data-poor areas. It has been applied to several regions across south eastern Australia including the Murray Group Limestone near the mouth of the Murray River, ‘Port Phillip and Western Port Bay’ and the riverine plains in northern Victoria.

Application to the Murray Group Limestone and Port Phillip and Western Port Bay have both produced highly plausible watertable elevation maps. There are no areas with unrealistic artesian conditions, which are often seen in valley floors using standard Kriging and other interpolation methods. The modelled water table maps also correlate strongly with measured groundwater elevations (see Figure 1), and cross validation produces good results.

This method suits the retrospective nature of the Bureau of Meteorology’s water reporting framework reports and is used to inform key products such as the National Water Account and Australian Water Resource Assessment report.

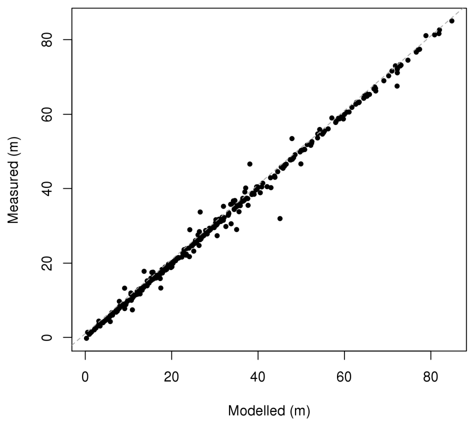

Figure 1. Observed vs modelled watertable elevation (mAHD) for the Murray Group limestone in the area of the mouth of the Murray River.

Keywords: *Groundwater, hydrogeology, watertable mapping, interpolation*

A novel image based end-member extraction technique to map green, non-photosynthetic and bare soil fractions using Landsat data

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Abstract: In most cases a single pixel in a satellite image contains information from more than one type of land cover substance. One challenge is to decompose a pixel with mixed spectral readings into a set of endmembers, and estimate the corresponding abundance fractions. The linear spectral unmixing model assumes that spectral reading of a single pixel is a linear combination of spectral readings from a set of endmembers. Most linear spectral unmixing algorithms rely on spectral signatures from endmembers in pre-defined libraries obtained from previous on-ground studies. Therefore, the applications of these algorithms are restricted to images whose extent and acquisition time coincide with those of the endmember library. We propose a linear spectral unmixing algorithm which is able to identify a set of endmembers from the actual image of the studied area. Existing spectral libraries are used as training sets to infer a model which determines the class labels of the derived image based endmembers. The advantage of such an approach is that it is capable of performing consistent spectral unmixing in areas with no established endmember libraries. Testing has been conducted on a Landsat7 ETM+ image subset of the Gwydir region acquired in Jun 2008. Three types of land cover classes: bare soil, green vegetation and non-photosynthetic are specified for this test. A number of ground abundance observations were obtained from a corresponding field trip. The study successfully identified a set of 256 endmember samples from the image for three specified land cover classes. For most test points, the spectral unmixing and estimation of the corresponding abundance are consistent with the ground validation data.

Keywords: *Spectral unmixing, endmember, convex hull, linear programming*

Combination of Spatial Forecasts

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Abstract: Linear combinations of model forecasts have been extensively used to combine forecasts in a temporal setting. Using two or more models, the prediction error of past forecasts is used to find the error variance for each model and the correlation between the model errors. This knowledge can be used to calculate a combination weight for future forecasts which minimizes the mean square error. In this paper, this method is modified for use in a spatial setting.

In the temporal setting a suitable window of previous prediction errors is used to calculate the combination weights. In the spatial analogue, instead of using a temporal window a suitable number of nearest neighbors is used. Errors at the nearest neighbor locations are calculated using interpolation with the location removed and then subtracting the known value from the predicted value. Using these leave-one-out errors from a suitable number of nearest neighbors allows the error variance for each interpolation method and the correlation of the errors for the interpolation methods to be calculated. A combination weight at the unknown location can then be calculated and used for combining the different interpolation methods and improving the spatial forecast.

In order to test the proposed method, the method of spatial forecasts was applied to different sized daily precipitation data sets covering differing extents of Sydney, Australia. In this particular example we chose to use two different types of copula interpolation for prediction: 'global' copula interpolation and 'local' copula interpolation. The global copula interpolation was based on using a copula where the copula parameters were estimated using the entire data set, whereas the local copula interpolation used a copula where the copulas parameters were estimated using a local neighborhood. This gave two competing interpolation predictions, both which interpolated the data well however resulted in different error variances. Although both methods performed equally well the use of the spatial combinations resulted in a consistent reduction in the prediction error. Using the two different data sets showed that the results are sensitive to the merit of the two competing interpolation methods, and best performance of combination of forecasts is likely to be obtained when both interpolation methods have similar merit. However, even when one model is consistently poorer, combining forecasts still resulted in an improvement above that of each individual method. Further sensitivity testing was performed on the choice of neighborhood for the calculation of the combination weights. Using both a local and global neighborhood for the estimation of the combination weights showed that using a local neighborhood gave better results suggesting that the most critical factor in improving interpolation forecasts is correctly estimating the error variance and correlation at the unknown location and future research will focus on improving the estimate or the error variance and correlation at unknown locations.

Although the method of combining spatial predictions is presented in the context of copula interpolation, it can be applied to any data set and interpolation problem where there are two or more spatial predictions being performed.

Keywords: *Interpolation, spatial, forecast*

Comparison of sum of two correlated gamma variables for Alouini's model and McKay distribution

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Abstract: A statistical model for rainfall is useful to describe the relationship between rainfall at a given location and other weather-related variables. It is also able to provide a principled way to quantify the uncertainty that associates rainfall processes, which is crucial to the efficient design of environmental projects and to improve crop production. Various statistical models have been used for rainfall such as a right-skewed distribution including the exponential, gamma or mixed-exponential to model the rainfall intensities and Markov chain model to model rainfall occurrences.

Two models of the sum of two correlated gamma variables, namely Alouini's model and McKay distribution are studied. Alouini's model is an extension of Moschopoulos results for the sum of n correlated gamma variables. There are two forms of McKay distribution, the Type I is defined for sum of two correlated gamma variables whereas Type II is defined for difference of two correlated gamma variables. In this study, the Alouini's model and Type I of McKay distribution are compared using monthly rainfall totals to form water catchment from two meteorological stations, Hume and Beechworth within the Murray-Darling Basin. Rainfall totals during the summer season at both stations are selected based on the significant correlations. The procedure for the analysis is as follows: (1) select positive pairs set of data from two stations (2) calculate the pairwise Spearman's correlation and check if the correlation is significant (3) fit the data marginally with the gamma distribution and use maximum likelihood estimation method to estimate the parameters for the gamma distribution (4) calculate the average value of shape parameters and re-estimate the values of scale parameters (5) apply the model to generate synthetic sum of monthly rainfall totals (6) compare the sum of monthly rainfall totals between the observed and generated data using the Kolmogorov-Smirnov goodness of fit test.

The results of the analysis show that the values of mean and variance of the observed and estimated from the McKay distribution is closer than the values of mean and variance estimated from the Alouini's model. Based on the Kolmogorov–Smirnov goodness of fit test, the P-value of observed versus McKay distribution is much higher than the P-value of observed versus Alouini's model. It shows that the McKay distribution fits the data better even though both models pass the test. However, when the Alouini's model and McKay distribution are compared, the rainfall totals generated by the two models fail the test of being from the same population. Zakaria (2011) shows that the Alouini's model is suitable in modelling the sum of four correlated gamma variables and can easily be extended to more than two variables. On the other hand, the McKay model is not easily extendable to more than two variables because of extensive algebraic manipulation. Thus, in this particular example of two stations and three months, it is instructive to note that the McKay formulation can well represent the sum of individual months at the two locations, but if we wanted to represent the sum over the three months of the season, we would have to use Alouini's method. Both models are able to be used to generate synthetic sum of rainfall totals and Alouini's model can be used to model the sum of more than two correlated gamma variables. It may well be that catering for this extra flexibility is the reason that the Alouini's model does not perform so well for the two variable case. In future work, we will be comparing these two approaches with other formulations as well, such as the use of Maximum Entropy methods.

Keywords: *McKay distribution; Alouini's model; correlated gamma variables; rainfall model*

Analysis of trends in temperature and rainfall in selected regions of Australia over the last 100 years

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Abstract: Climate change has a significant impact on the environment as well as the social, economic and political fabric of Australia. This paper examines historical trends in temperature and rainfall in regions of Australia which represent different climatic regimes.

In this study, we analyse trends in temperature and rainfall in three selected regions (Central eastern Queensland, south west Western Australia and central east Victoria) over the past 50-100 years. Observational data for daily maximum temperature, daily minimum temperature, daily mean temperature and total annual rainfall recorded at meteorological stations in these regions have been obtained from the National Climate Centre, Australian Bureau of Meteorology (BoM). Historical trends in the observational data have been examined using time series analysis. The results indicate that Australia is experiencing rapid climate change. Over the last 100 years, Australian temperatures have increased on average by approximately 1°C. Rainfall distribution across the continent has changed during the last century and even more pronounced changes in rainfall patterns are evident over recent decades. Since the 1950s, an increase in rainfall in the northwest of Australia has been observed. In contrast, significant decline in rainfall over eastern and south-western Australia has been recorded. Consequently, such trend as well as changes in rainfall and temperature patterns have manifested in changes of frequency of climate extremes such as droughts and floods.

Detailed results of trend analysis of rainfall and temperature are presented. The results of this study are in good agreement with the findings of early studies.

Keywords: *Climate change, temperature, rainfall*

Multifractal analysis of wind farm power output

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Abstract: Wind generated power is subject to fluctuations due to the intermittent nature of wind which causes unpredictable energy provision. Electrical power is not easily stored so the generation of power ideally would match demand. The amount of energy provided by wind, (and solar power) is determined by natural events which makes matching supply and demand very difficult. Wind speed data has been used in the past to assist with the prediction of power generation, but it is not a satisfactory predictor.

There have been numerous attempts to identify the characteristics of wind speed time series data and it has been found in previous studies that they exhibit long term dependence. Methods of analyzing wind speed and power output time series data have included traditional time series analyses such as ARMA and GARCH as well as the relatively new methods of detrended fluctuation analysis (DFA) and more recently multifractal detrended fluctuation analysis (MFDFA). This study extends these latter methods to examine the variation of output that is inherent in wind generated power.

Almost all chaotic systems can be characterized by a fractal dimension. The fractal dimension of an object is a measurement of a non-integer dimension which represents the degree of persistence, also known as scale or self similarity, embedded in the series.

The history of the Fractal Dimension Index (FDI) begins with the British dam builder and hydrologist H.E. Hurst, in 1951. He worked on the Nile River Dam Project searching for patterns in the Nile delta to solve problems related to the storage capacity of the dam reservoir.

Most hydrologists assumed that water inflow was a random process with no underlying order. After studying almost a millennium of Nile overflows Hurst found that large overflows tend to be followed by large overflows most of the time. There appeared to be cycles, but their lengths were non-periodic. Standard statistical analysis revealed no patterns between observations, but the concept of persistence was raised.

Hurst divided the Nile data into time segments and examined the variance of each segment in comparison with the number of total segments. The process is called re-scaled range analysis. Using this analysis Hurst showed that overflows tended to repeat, meaning that the natural overflows were partially predictable.

Mathematician Benoit Mandelbrot, used the Hurst exponent to experiment with time series found in nature. This led to his development of a method to measure the irregularity in natural objects. He named the measurement the Fractal Dimension Index. The development of fractal geometry in recent times has provided a means of characterizing a range of complex structures using the concept of the fractal dimension. The fractal dimension, which is not necessarily an integer, reflects the scale symmetry of random structures which include time series, and is measured by the Fractal Dimension Index (FDI). Scale symmetry refers to the self similarity patterns observed on different time scales, and a single scaling exponent characterizes the structure. The FDI determines the volatility, which is the unexpected event of extremity, of a given time series. This specialized indicator identifies the Fractal Dimension of the series by using re-scaled range analysis and an estimated Hurst exponent. This has been used by researchers to determine the persistence or anti-persistence of a series.

Previous studies have found that the wind farms in South Australia have some spatial correlation, but that it is not sufficient to be able to aggregate analyses into more than one farm. The farms are thus analysed individually, to assess the degree of persistence in the data for five minute time intervals. The results show that there is evidence of persistence in some of the wind farm time series data under study.

This paper describes the application of the MFDFA technique to a set of wind farms located in South Australia.

Keywords: *Multifractal detrended fluctuation analysis, wind farms, electricity generation, prediction*

Modelling the spread and growth of *Caulerpa taxifolia* in closed waterways in southern Australia using cellular automata

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Abstract: This study presents the mathematical development of a cellular automata model for the species *Caulerpa taxifolia* for closed or intermittently closed waterways along the Australian coast. The model is used to assess the spatial coverage of *C. taxifolia* by describing changes in growth, spread and total biomass for the species. Building upon a foundation model developed by the authors, this study was designed to enhance the predictive capabilities of a model based upon a discrete version of Laplace's equation. The improvements relate to several components integrated into the Laplacian coefficients; a periodic function which represents the seasonal variations in growth, the incorporation of the prevailing wind to represent the most likely direction of spread, and growth restrictions based on lake depth. The additional complexity improved the predictive capability of the model.

Cellular Automata (CA) have been used to model changing plant distributions over the last 20 years, providing efficient models for complex environmental systems, particularly of exotic species. In this project the discrete CA algorithm is designed to determine the state or biomass $B = \{-1, 0, 1, 2\}$ of the current cell using the primary rule of the discrete Laplacian system. Biomass of -1 refers to land, and the other values represent the relative quantity of the weed in the cell; none, sparse or dense respectively. Cell interactions are governed by the coefficients of the Laplacian system which is discussed.

The foundation model incorporated simple rules, not unlike those of John Conway's Game of Life. The biomass of the surrounding cells at time t determines the state of the central cell at time $t + 1$. The boundary conditions were catered for by allocating a biomass of negative one to the land cells adjacent to the water.

The results indicate that the model is able to predict the total surface coverage and total biomass at levels of accuracy commensurate with the input data, which is important for control measures. Also, high accuracy in the predicted locational data at Lake Conjola indicates that the model is able to identify appropriate growing conditions to aid in the eradication efforts. At successive time steps, the model produces accurate patch location data with a slight overestimation on patch size due to slight error prediction of the decay in the initial winter season.

The principle objective of this new study is to improve the predictive capabilities of the model developed by the authors, by taking into account the biological and environmental factors of growth and spread and in doing so, more accurately predict the spatial coverage and colonization locations of *C. taxifolia* growth and spread in a closed or intermittently closed estuary. This model is designed to inform resource managers and government bodies of the most effective methods of eradication.

Keywords: *Caulerpa taxifolia*, cellular automata, biomass dynamics, Laplacian system

An Investigation of Cool Roofing on Urban Street Canyon Air Quality

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Abstract: The installation of cool roofing in urban areas is a practical mitigation measure to reduce the Urban Heat Island (UHI) effect and is currently being implemented in many cities around the world to reduce building cooling load demands. The UHI effect results from surface and air temperatures of urban areas being higher than rural areas due to the thermal properties of buildings and reduced vegetative cover. Examples of cool roofs are white vinyl roofs and roofs with reflective coatings. Cool roofs have high albedo (also known as solar reflectivity or solar reflectance) which helps to reflect sunlight and therefore, reduce roof temperatures. Lower roof temperatures result in lower internal temperatures within buildings and this significantly reduces their cooling load. A street canyon is an representative unit of an urban area whereby a street is flanked by two tall buildings on both sides. The aim of this study was to investigate the effect cool roofing has on the air quality within a street canyon. In this project, an idealised street canyon with a street canyon height-to-width ratio of one was created in a Computational Fluid Dynamics (CFD) model which utilises the Renormalization Group (RNG) k-ε turbulence model. In order to verify the model's ability to simulate thermal effects, the CFD model was first validated against experimental results from an atmospheric diffusion wind tunnel in a study carried out by the Japanese National Institute for Environmental Studies. Then, the validated CFD model was run with two different roof temperatures to investigate the effect of a cool roofing product's cooling intensity on the street canyon. In the model, a constant area source of pollutant mass flow was generated at the bottom of the street canyon to simulate road traffic emissions. Selected air quality indicators such as Air Exchange Rate (ACH), Pollutant Exchange Rate (PCH) and Average Volume Mass Fraction (Θ) were then used to analyse the modelling results. The analysis indicated that the air quality within the street canyon is improved marginally as a result of cooler air entering the street canyon due to negative buoyancy generated by cool roofing.

Keywords: *Cool roofing, Urban Heat Island Effect (UHI), air quality, urban street canyon, Computational Fluid Dynamics (CFD), Renormalization Group (RNG) k-ε turbulence model*

Detecting the infrastructural, demographic and climatic changes on macroalgal blooms using cellular automata simulation

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Abstract: Worldwide, the effects of anthropogenic nutrient loading into estuaries include a shift from sea grass to macroalgae, particularly the "bloom and bust" cycle of the ephemeral Chlorophyta. Macroalgal blooms only occur in spring and summer when rainfall prior to and during this time is low. This study describes temporal and spatial dynamics of nuisance macroalgal blooms in Avoca Lake, an intermittently closed and open lagoon lake (ICOLL) in NSW, Australia and identifies the main factors influencing algal growth in that lagoon.

The dynamics are modelled using discrete cellular automata (CA) and a set of algorithms to capture the spread of the blooms. The objective at this stage is to identify the factors that contribute to the spread and ultimately to identify the factors that cause the initial outbreaks. Water temperature, salinity, dissolved oxygen, turbidity and bioavailable nutrients (nitrogen and phosphate) were measured, at weekly intervals, throughout the Lake during the major bloom which occurred in late 2012 as these variables are all considered likely candidates for blooms.

Salinity and light were identified as two most important factors influencing algal growth; blooms always started at the shallow edges of the lake or around seagrass patches where algae attached to seagrass blades were positioned closer to the surface. No bloom occurred during the same period of the previous year when there was a lot more rainfall and much lower salinity in the ICOLL.

Aerial photographs taken on four occasions over this period were digitised to record the extent of macroalgal cover. The CA model is initialised using knowledge of the behavioural dynamics of the algae; notably, that usually they are first observed at the edges of the ICOLL, where the water is warm and the light is good, due to the shallow water level. Later models will be initiated with observed data at the start of the 2012 bloom and validated by comparison of the simulated data with the observed.

The CA model presented in this work is a further extension of the model developed by the authors. The discrete-Laplacian description for biomass provided a method to describe the spread and growth of algae, which incorporated currents, seagrass distribution, water depth and other parameters. The results of the present study highlight that when developing a model to predict the occurrence, spread and duration of macroalgal blooms in this ICOLL; such a model must include detailed data on dissolved oxygen, turbidity, salinity and nutrients. Additional complexity arises from the periodic opening of the ICOLL to the ocean. This also influences algal biomass dynamics, and the model will assist with determining the effect of the opening on the dynamics.

Keywords: *Macroalgal bloom, Avoca ICOLL, cellular automata, parameter optimisation, simulation modelling*

Optimisation modelling for gas supply in Eastern Australia

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Abstract: The security of gas supply is a crucially important question for economic of any country. South-eastern Australia has a sophisticated network of gas pipelines which connect the productions sites in the ocean shelf and in the inner part of the continent with major consumers which are capital cities (Adelaide, Melbourne, Hobart, Sydney and Brisbane) and major seaport of Gladstone in Queensland where gas is liquefied and then shipped to the Asian market. Two optimisation models were developed in order to test the satisfied demand security of the gas supply system to the possible global impacts which affect the demand for natural gas. The modelling research in the present work was focused on the simulation of delivery when demands reach their peak values. The first model minimises shortfalls in major supply nodes. As major constrains models used the production levels, supply capacities and mass balance in pipe junctions. The second model minimises the total cost of the gas delivery, which is a sum of production and transportation costs, whereas the constraints mostly stay the same. Both models were run for a series of the plausible economic scenarios which generated the future values of demands. The potential "bottle necks" in the system components were identified. It was found that the first constraint which became scarce is the pipe providing gas to the port of Gladstone. The capacity of this pipe should be increased in order to facilitate the increase of export from Gladstone, but will reduce supply to other consumption nodes.

The first model focused on the shortfall minimisation can be considered as a decision support tool for gas delivery reallocation. It can help relevant authorities to obtain maximum security (or minimal risk) in the gas delivery network system, which is treated as elimination of problem related to the gas supply shortfalls for the time when demand level reach their peak values. Despite of simplifications admitted in this model it should be noted that it is a first step in the direction of risk management for the gas supply in South-eastern Australia. In present formulation the equal penalties are assigned to shortfalls in all demand nodes. This is the major problem associated to the shortfall minimisation model. At present there is no information available which would make possible the differentiated approach to the shortfalls in different demand nodes. This could be one of potential directions of future research work.

The second model formulated in the present work minimises the cost of supplying gas to consumers. The model includes both the cost of production and the cost of transportation. Much of the research on gas transportation focuses solely on transportation costs and neglects the cost of production. However, the cost of production is highly variable across gas basins, and even across fields within the same basin. Natural gas is often found with heavier hydrocarbons such as propane or butane, and with liquid hydrocarbons like crude oil, with the gas often being the least valuable product. This can mean that natural gas is essentially a by-product of production with little value. Therefore the variability of production costs is of interest to owners of transmission pipelines, who may see the volume transported through their pipes decline if production costs rise and large gas users find alternative sources of supply. It is also of interest to industries that may be appraising different regions for the construction of new plants, factories, or gas generators.

The sensitivity analysis was implemented for both formulations of the model. The objective was to examine how the key indicators of system security and pipelines' flow were impacted by the changes (increase and decrease) in peak demands. For this sensitivity test the predicted annual scenarios for peak demand increase for four states (ACT was treated as part of NSW in present work) were used. For the analysis of the decrease of demands the equal proportional changes in demand were used for all demand nodes. It can be concluded that under current infrastructure the most vulnerable components of the system are industrial gas users in Galdstone and Mt. Isa (both in Queensland), whereas amongst the domestic consumers it is Brisbane. This conclusion can be utilised in further decision on the pipeline infrastructure upgrade.

Keywords: *gas supply, linear programming, quadratic programming, network optimisation*

Multi-Model Ensemble Simulation of Flood Events using Bayesian Model Averaging

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Abstract: Flood event simulation using hydrological model is subject to various uncertainties. Multi-model ensemble simulation approach has proved to improve forecasting uncertainty by reducing the systematic bias in comparison with its single model. In this paper, the Bayesian Model Averaging (BMA) approach, a statistical scheme based on multi-model ensemble, was applied for flood prediction and uncertainty estimation of flood event predictions in Qingjianhe Catchment. Five hydrological models including GR4J, HYMOD, Simhyd, XAJ and modified SCS were employed and calibrated with two objective functions NSE and WR^2. Ten ensemble simulations were then used for further BMA analysis. The results showed that the five hydrological models performed reasonably well in QJH catchment, but with significant difference in the simulated hydrographs. The modified SCS model performed the best among the five models in term of NSE and WR^2. The BMA weights for the model prediction were roughly consistent with the model performance. GR4J model weighted higher than other models. Predictions with BMA median performed less well than those from the best individual model SCS, especially for peak flows. However, BMA gave more reliable predictions. For most flood events with different recurrent periods in the study catchment, the 50% confidence interval seemed sufficient to bracket the observed flood discharge. It indicates that BMA approach is helpful in reducing uncertainties, thereby increasing the level of confidence in prediction results. The prediction uncertainty quantified via BMA can be very helpful for decision makers to develop flood management strategies.

Keywords: *flood event, hydrological model, ensemble simulation, BMA*

Characterising Mineral Slurry Dewatering through Laboratory Centrifugation

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Abstract: Water plays a key role in the mining industry, mainly in supporting exploration and mineral extraction. Cost efficiency can be obtained by minimising the use of water. Efficient methods of water use minimisation during the recovery process are suggested to build on a framework for modelling and simulation of mine water use during dewatering. Dewatering can be described by a one-dimensional model for a thickener, centrifuge or pressure filter, where the local solids concentration depends on time and position.

The dewatering dynamics is described by two material-specific model functions of the local solids concentration ϕ: The hindered settling function $R(\phi)$ quantifies or hydrodynamic resistance to flow of liquid through the slurry. This resistance is mathematically related to a solids settling flux function $f(\phi)$. When all particles are in contact, i.e. when the local particle concentration is greater than the gel point, the slurry forms a continuous network and has a network strength that can transmit stress. The compressive yield stress $P_y(\phi)$ or effective solids stress function $\sigma_e(\phi)$ quantifies the strength of the particle network in compression, with the strength being zero at the gel point ϕ_g or critical concentration ϕ_c.

In order to obtain a scalable model, the dewatering model can be calibrated on laboratory scale with help of a laboratory centrifuge and an algorithm for parameter identification. In centrifugation, the tailings slurry is described by its local solids concentration (volume fraction) $\phi = \phi(r,t)$ as a function of radial position r and time t. As a model simplification, it is assumed that the sludge has a relatively homogeneous composition, i.e. it is composed of uniform solid particles having same material properties like an effective average diameter and density. A slurry that only consists of one single type of particles is referred to as a "monodisperse" suspension. The settling of a monodisperse flocculated suspension in a rotating tube centrifuge can be modelled by the following spatially one-dimensional partial differential equation (PDE)

$$\frac{\partial \phi}{\partial t} + \frac{\partial}{\partial r}\left(-\frac{\omega^2 r}{g} f(\phi)\right) = \frac{\partial^2 A(\phi)}{\partial r^2},$$

where ω is the angular velocity, g is the acceleration of gravity, the batch hindered settling function $f(\phi)$ is the first of two material-specific model functions of the local solids concentration ϕ, and $A(\phi)$ is a diffusion function depending on both $f(\phi)$ and $\sigma_e(\phi)$.

Two applications of this PDE earlier described by Berres et al. (2010) and Usher et al. (2013) are compared for their utility in determining material properties for process modelling. For the first method, the constitutive functions are given in parametric form; the parameters are identified by solving an inverse problem through an optimisation routine. The gel point turns out to be a highly sensitive parameter which induces a natural ill-posedness. By the second method, the raw measurement data is used to characterise material property values at a number of solids concentrations. These data can then be fitted to determine parameters for constitutive functions. Both methods deliver functions for the phenomenological description of mine water dewatering.

Keywords: *Dewatering, gel point, Centrifugation, Numerical modelling, Sedimentation, Compression, Flocculated Suspension, Parameter Identification, Sensitivity Analysis*

A process-based simulation model for strategic mine water management

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Abstract: Substantial expansion of the mining sector in Australia has resulted in increasing demand for freshwater. The increasing demand is set within the background of augmenting water allocations to environmental flows and changing climate. Such situations have forced the mining sector to improve its water resource management. Scientific tools are urgently needed to predict outcomes from new management options that affect water supply security, water use efficiency, water use cost, and risks associated with discharges.

We present a new system model that integrates a water use process for assessing complicated mine water use strategies. The operation rules of mine water management strategies can be placed on model objects and process states. Its implementation follows the water accounting framework for the minerals industry.

A case study in the Bowen Basin in Queensland, Australia is included to illustrate the benefits of such a model, and a set of mine water use strategies are also assessed and compared. The results show that a process-based model is an appropriate tool to provide guidance on improving mine water use management.

Keywords: *mine water management, modelling mine water use, water strategy evaluation, water resources management, mining*

Secure mine water use with compliant discharge

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Abstract: Water is of great need by a broad range of mining activities, and is becoming more valuable due to growing demand and increasing scarcity. Following years of dry conditions, most mines in Queensland, Australia have been designed to highly reuse water and catch as much runoff as possible. However, during significant rainfall periods, unregulated mine water discharge may result in significant external environmental impacts, which lead mine water managers to reconsider the water management strategies. In particular, a careful balance needs to be struck between securing a 'fit-for-purpose' water use during water limited periods, on one hand, and reducing the risk of unregulated discharges from mine sites when water is in excess, on the other.

A solution suggesting that actively regulated discharge can be used to reduce the risk of occurrence of unregulated discharge has been placed at the disposal of mine water managers. The study aims to examine the feasibility of the solution. To do this, we used a system model called SMART to produce the trade-offs between securing water for mine production and minimising unregulated discharge. The model combines a simulator of mine water use and a multi-objective optimisation scheme. We applied the system model into a coal mine in the Fitzroy Basin, Queensland, Australia. The results demonstrate that unregulated discharges can be significantly reduced in the case study mine site. The successful use of mine water management strategies, such as formulating discharge regulations, requires a tool capable of providing scientific advice. Models similar to the one used in this paper can assist mine water managers in finding more balanced strategies under multiple management objectives.

Keywords: *mine water management, modelling mine water use, water resources management, mining, multi-objective optimisation, unregulated discharge*

A multi-criteria evaluation of water management for sustainable development in mining

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Abstract: Mining is a water intensive activity. Mining companies are expected to bear responsibility for their impacts on water resources. Mine water management is a significant issue for sustainable development to maximise shareholder's value, secure production, and minimize environmental impacts. The identification of sustainable mining water management practices is technically challenging because of the lack of scientific tools available to evaluate optimal decisions.

The paper proposes a multi-criteria evaluation method that aims at selecting reasonable water management practices for sustainable development in mining. The method is based on the analytic hierarchy process (AHP) together with a technique for order preference by similarity to ideal solution (TOPSIS). Water must be managed at all stages of the life cycle of mining operations. However, the focus in this paper is the evaluation of mine water management practices at the mine operating stage. A decision hierarchy and a criterion set for assessing sustainability of mine water management were proposed, and used to evaluate management practices in six coal mines in the Bowen Basin. The AHP method was used to determine the weights of evaluative criteria. The ranking of the mine water management practices was calculated with the fuzzy TOPSIS method. The evaluation results illustrate the usefulness of the proposed method in identifying leading mine water management practices. Finally, some management implications were derived from the work to improve water management towards a more sustainable mining industry.

Keywords: *Mine water management, Multi-criteria evaluation method, Sustainable development, Analytic hierarchy process, Fuzzy TOPSIS*

A Scenario Model for Mine Water Management under Extreme Climate Variability

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Abstract: Managing mine water under extreme climate variability requires the capability to find trade-offs among multiple competing goals. In order to identify the relationships among these goals, we need to carry out case studies in selected mines based on those events happened in the past and those might occur in the future. However, these types of case studies are often isolated and lack of coherence when an optimal solution is sought at a regional scale with multiple mine sites. One of the key challenges is the lack of the context and scope for identifying and quantifying the causal and inter-dependency relationships among the factors that constrained the competing goals. Therefore it is difficult to capture the actual requirements which are essential to the development of a decision support system for mine water management.

This paper presents a holistic approach to capturing the requirements for mine water management through the design of a scenario model for supporting case studies. The scenario model is depicted through three perspectives: the business perspective shows the mining activities and decisions according to their business hierarchies, such as within a mine or across several mines or companies. The profiles of a number of mines are collected and anonymised to form a hypothetical mining company and put into a geographical location under investigation; the environment perspective represents all the climate change patterns, such as rainfall and catchment histories and weather forecast data; the decision perspective demonstrates how alternative decisions on water management strategies would impact on the operations of the given mine sites in the selected environmental conditions.

A number of case studies have been constructed based on the designed scenario model, such as the proactive water management according to weather forecasts, the assessment of the effectiveness of water sharing and trading among multiple mine sites, as well as the evaluation of the costs and benefits of establishing water management infrastructure in mine sites.

Keywords: *Mine Water Management, Scenario Modelling, Requirement Engineering, Case Studies*

A phenotyping platform for transgenic wheat: method and initial results

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Abstract: In recent years, the interest in new technologies for wheat improvement has increased greatly. As methods for conventional and molecular breeding have advanced, more efficient procedures for phenotyping have become a bottleneck. At the Australian Centre for Plant Functional Genetics (ACPFG), a centre for the improvement of wheat and barley's tolerance to environmental stresses, we developed a phenotyping platform for transgenic wheat and barley. After the initial selection of single/low copy number plants in the T0 generation, the T1 and T2 generation are screened under competitive growth conditions in large plastic bins. At present, the setup consists of 32 bins which can be used two times a year. All bins are fully equipped with irrigation system and sensors for soil water tension, soil temperature, air temperature, and air humidity, recording data at the time step of 5 minutes. The T1 generation is preferably grown in the summer season (January to June) whereas the T2 generation is evaluated in the main growing season (July to December). The first screening of T1 plants serves to remove off-types (for growth duration, plant height, and other growth anomalies) and to select homozygous plants. In the next step, T2 plants are phenotyped under different soil water and nitrogen regimes in a replicated experimental design in comparison with the wild type and null controls (drought and nitrogen response traits). Plant traits recorded in stage 2 for each individual plant were: tiller number, spike number, empty spikes, plant height, number of seeds, seed weight, and above ground biomass. The soil moisture tension curves of the drought treatments did show a gradual water stress increase over several days to weeks, closely mimicking field conditions. The observed average grain yields per plant were realistic for both well watered and droughted conditions, but seemed still to be too high under the low fertility regime. However, interpreting grain yield data from this setup remained difficult mainly because of the relatively high variability between replications. Further trials are needed to show if this variability can be reduced. We concluded that the new high throughput platform for the testing of transgenic wheat growing in a field-like situation but under controlled conditions was functioning. First season results showed that screening conditions for drought and nutrient use efficiency were as planned and that the platform served its objective. Improvements of the platform to achieve more homogenous results are outlined and the establishment of a digital imaging and analysis system is ongoing. These changes are intended to further increase the diagnostic value of the platform.

Keywords: *Competitive growth conditions, drought, nutrient use efficiency, phenotyping, wheat*

Generalised linear model and analysis of cereal plant biomass

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Abstract: Numerous literature discuss methods, models and results achieved by applied image analysis techniques in order to deduce plant information. Although all methods required data from destructive testing their recommendations suggest the expansion of their methods onto an automated system is within reach. This new system will provide a quicker, cost efficient non-intrusive way to gather plant information as an alternative to destructive testing. The estimation of plant biomass is important to many applications such as plant breeding and agriculture. The generic biomass model presented here is based on the separation of plant components which opens up the potential to account for the structural and density differences of plant components.

Various statistical techniques have been employed to assess the improvement of previous biomass models and challenges which arise when regression models do not conform to assumptions. This paper offers an alternative model which preserves the original data and linear model template, yet accounts for increasing systematic variability present in the data. Both informal and formal statistical methods were used to asses the goodness of fit and comparison between the commonly used method of least squares regression and the generalised model proposed here.

These models are an extension to those found in literature of plants under experimental conditions and the intention is to apply this model coupled with image analysis in order to deduce plant information in a non-intrusive way. The proposed biomass models presented here aim to combine image processing techniques with mathematical modeling in an effort to replace destructive testing.

Keywords: *Cereal biomass estimation, image processing, ordinary least squares, generalized lineal model, analysis of deviance, Akaike Information Criterion*

Selection of Parameters in Active Contours for the Phenotypic Analysis of Plants

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Abstract: Modern genomics experiments are often conducted in controlled environments on hundreds of plants at a time. As such, manual and destructive phenotyping techniques are no longer suitable. Recently there has been a trend toward automated high-throughput phenotyping facilities, in an attempt to relieve the phenotyping bottleneck. A majority of these facilities focus on the use of cameras for non-destructive recording of plant data. Hence, the new challenge lies in accurately segmenting the plants from 2D images in an automated manner and then analysing structural and statistical information about them.

One such technique for image segmentation is known as the active contour model. Active contour models have seen widespread success throughout a number of applied fields due to their versatility and semi-automated nature. However, a high majority of these models rely on arbitrary parameters that are required to be selected manually. Furthermore, small variations in these parameters can produce substantial variations in the method's overall accuracy. This makes them unsuitable for use by non-experts and also for the analysis of a series of images that can change significantly over time. For example an image sequence for the growth of a plant.

In this paper we attempt to establish relationships between the parameter values of active contour models and the geometry of the objects/shapes that they are segmenting. Our goal is for users to be able to utilise some basic *a-priori* knowledge about the geometry of the object in order to automatically select a range of suitable parameter values. We analyse the accuracy of active contour models over multiple series of shapes that exhibit some pattern, such as decreasing number of sides or increasing concavity. We present a novel normalization technique so that the parameter values are of a similar scale. We also carefully design an experimental setup that ensures no bias between different shapes or parameter values.

We show that over a series of shapes the range of parameters that provide convergence do follow a trend. We also show that not all contours that converge to the objects boundary do so in a stable manner, with a substantial amount oscillating continuously. However more information, such as more shapes and more parameter values, is required to draw meaningful and quantitative conclusions from such an analysis. Future work includes incorporating more of this information along with the application to more active contour models. Another exciting future direction is the use of 2D shape diagrams to quantify relationships between shapes, parameter values and levels of accuracy.

Keywords: *Active contours, parameter selection*

3D Reconstruction, Modelling and Analysis of in Situ Root System Architecture

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Abstract: Root system architecture (RSA) plays an important role in water and nutrient uptake for plant development and growth and hence in grain yield. In situ studies of RSA root architecture will assist in the characterization of phenotypes for the purpose of identifying genotypes of cereal plants that are more stress tolerant and are producer of higher grain yield. In this paper we present a method of 3D reconstruction of roots with a non-destructive method, preserving the RSA and also allowing for observation of the roots growth as function of time.

Our method was applied to corn plant seedlings in their early stage of growth. The germinated corn seeds are grown in a transparent gel-based growth system. Observations are made with a digital camera with the growth chamber sitting on a turntable, at different time instances of the growth. The digital images are processed for segmentation of roots, root tip detection, and root tips are tracked as a function of angle of the turntable motion. The elliptical trajectories of the root tips are used to calibrate the cameras. After calibration of the imaging sensor the 3D reconstruction and modelling of the roots are done using the visual hull (space carving) algorithm. We analyse different stages of 3D root developments in terms of roots volume as a function of time and the number of images used in reconstruction of the RSA.

Our results show that root biomass/volume increases with time. This trend is true irrespective of the number of images used for 3D reconstruction. The increase in root volume is approximately linear with time for plants is in the early stage of growth. It is not very clear what will be the optimal number of images to use in 3D reconstruction and modelling. Less number of images require less acquisition time and less processing time, which may be important for high throughput systems. By visual inspection it can be said that the 3D reconstruction becomes more accurate and detailed with increasing number of images. We empirically verify that the volume of reconstruction monotonically decreases increasing number of images from different viewpoints. This is due to erroneous voxels being carved out when information from more images are being added to 3D reconstruction.

Keywords: *3D Reconstruction, Root System Architecture, Temporal Growth Analysis, Gellan gum*

Curve-based Stereo Matching for 3D Modeling of Plants

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Abstract: Realistic image-based 3D reconstruction of narrow plants, such as wheat and barley, is challenging because of plant's lack of a well defined surface, complex self-occlusions, and high degree of self-similarities. In this paper we present a new approach for image-based modeling of plants using a pair of cameras in a stereo setup. Our key idea is that while color and texture features are unlikely to match across images, local leaf shape, in particular the shape of its boundary curves, will. We propose a stereo matching algorithm that uses boundary curve features to build a dense depth map. We show that the local orientation of boundary curves can be used to recover the 2D leaf structure of plants, which in turn can be used for matching plant leaves across multiple views in a narrow baseline stereo setup. The proposed method is robust to slight movements of the leaves during imaging, which is an important concern in phenotyping narrow and fragile-leaf plants. We demonstrate results on a number of plants with varying complexity and discuss the performance and limitations of the proposed framework.

Keywords: *Plant phenotyping, orientation fields, 3D reconstruction, plant phenotyping*

Applications of image processing in viticulture: A review

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Abstract: The economic importance of the wine industry worldwide is driving the development and application of innovative methods and technologies for monitoring vineyards. The harvest can significantly vary from year to year and also within the vineyard due to soil conditions, disease, pests, climate and variation in vineyard management practices. Current practices for yield and quality estimation are destructive, expensive, inaccurate and largely subjective. These factors make the production of high quality grapes for wine making challenging. Image analysis has the potential to provide an inexpensive, non-destructive way of capturing precise information about the entire vineyard.

This paper presents a review of recent research relevant to the application of digital image analysis to the management of vineyards focusing on the key challenges for in-field, on the vine, ground level image capture and analysis. The applications explored are:

Yield Estimation: Historically efforts have primarily been focused on the objective estimation of harvest yield. In order to estimate yield using image processing the grapes must be detected, segmented from the background and the number of clusters counted and the size of the cluster determined and this is typically how most estimation methods, using images, are approached. However for accurate yield forecasting berries within the cluster must be counted and the size of each berry determined. This is difficult to achieve due to the occlusion of berries. Many of the most successful grape detection methods have been developed, independently of the work on yield forecasting, for the automation of vineyard management activities such as harvesting and smart spraying rather than for yield estimation.

Quality Evaluation: Berry quality can be linked to visual properties such as the size, weight and colour of the berry. These properties have been proven to be indicators for ripeness and level of phenolics, flavonoids and sugar. To date most of the work in this area has focused on the processing of images of individual grapes in the laboratory. In the natural environment approaches must be able to cope with difficult and variable lighting conditions and with factors such as occlusion of the grapes within the cluster and by the canopy.

Disease Detection: While some work has been undertaken towards the detection of powdery and downy mildew and botrytis in grapes there is still significant scope for improvement. Detection in the field is difficult as the grapes may be covered by bloom and disease can exhibit different signs and symptoms depending on the grape variety and the stage of development of the disease. Moreover, more than one disease might be present. Current work does not address the issues of more than one disease or identification of the disease at various stages in its development. The most successful work to date has not been on in-field images.

Grape Phenology: The phenology of the grape vine is complex. Understanding the phenology of a given plant system is important in determining the ability of a region to produce a crop and knowledge of a plant's growth stages is advantageous as management practices (such as irrigation, pest and disease control and pruning) can be applied at optimum times in the vines growth cycle. Additionally, information regarding growth stages can be useful in forecasting crop yields and even quality.

The information gathered from automated, fast, accurate image analysis from in-field images could be used to design, train and validate simulations and forecasting models of vineyards and grape phenology. This type of research is at the forefront of climate research in which novel methods are required to monitor spatio-temporal physiological responses of food sources to changes in the environment.

The use of image processing to enhance vineyard practices and forecast the success and or quality of wine grapes is in its infancy. While much of the work to date is promising we have not yet achieved the "vineyard of the future", where image analysis (image and video) is a powerful tool that is adopted by viticulturists to inform the management of their vineyards.

Keywords: *Image processing, classification, viticulture*

Using UK-DNDC for the evaluation of legume-based rotations in European organic agriculture

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Abstract: Legumes are an important source of protein and have the potential to make an important contribution to European farming. The distinctive and common feature of almost all legumes is the symbiotic association with bacteria through which inert atmospheric nitrogen is "fixed" or converted into reactive forms. This supplies both the legume plant and the surrounding soil with nitrogen, thus reducing the need for inputs of nitrogen based fertilisers in the following crops of the rotation and hence reducing fossil fuel consumption and greenhouse gas emissions. While grain legumes may be consumed directly, their leaf material is either used as a green manure to fertilise soil, or processed to feed animals, commonly livestock and more recently fish. Although the use of legumes in Europe has increased in recent decades (particularly for livestock feed), their cultivation in Europe has declined, as they have been replaced by soya imports mainly from South America.

Legume Futures is an international research project in the EU Framework Programme 7 that addresses the environmental implications of reduced legume cultivation in Europe. As part of the project, new rotations incorporating legumes are being designed for use in European agricultural systems. The environmental effects, specifically N2O emissions, of these new rotations have been assessed using the UK version of the biogeochemistry model DNDC (**D**e**N**itrification**D**e**C**omposition). DNDC was originally developed for the prediction of carbon sequestration and greenhouse gas emissions from upland agro-ecosystems in the United States. In common with DNDC, UK-DNDC is a dynamic and deterministic model of the soil carbon and nitrogen cycles and plant growth processes and contains modifications that enable better representation of UK and continental European agricultural systems, predominantly with respect to grazing.

Differences in the environmental impacts of traditional rotations (non-legume based) and legume-based rotations were determined by scenario testing for five countries in Europe: Sweden, Germany, Italy, Scotland and Romania, which represent the following agro-climatic zones: Boreal, Continental, Mediterranean North, Atlantic North and Pannonian, respectively. For each country, rotations have been generated to represent an arable and livestock components of a mixed farming system. Using UK-DNDC we have compared rotations of similar crop composition and financial importance for the farmer. The arable components of legume based rotations were dominated by grain legumes (e.g. faba bean, pea, soybean) and for livestock the forage was mainly grass-clover. The climate data that were used were historic weather data (2000 to present) for each country. The modeled results for the Italian scenarios showed that the inclusion of legumes in a 4-year rotation sequence could reduce the accumulated N_2O emissions by ~30%. A sensitivity analysis for the effects of soil texture, using input data for the two dominant soils of each country has also been performed.

The purpose of this paper is to describe the assessment of biological productivity and environmental consequences of whole farm-scale adoption of novel cropping systems seeking to optimise the contribution of legumes to forage, pasture and arable cropping across the pedo–agroclimatic zones of Europe via a computer-based modelling approach.

Keywords: *Legumes, nitrous oxide , scenario testing, UK-DNDC*

Modelling the response in streamflow to increased forestry plantations

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Abstract: Plantation forestry is an important land use in Australia which has the potential to reduce water yields compared with existing agricultural use. However, because of the biophysical complexity of landscapes, the hydrological impact of plantation expansion will vary between catchments and between locations within catchments. This paper investigates whether incorporating the history of plantation expansion in a catchment improves the prediction of streamflow by capturing the lag in catchment water balance and streamflow response in response to changes in plantation area and age.

The study area for this project was the Glenelg Hopkins Region, South West Victoria, Australia; specifically the Crawford River, Eumeralla River and Darlot Creek. These catchments were selected as they were historically dominated by pasture based agricultural systems (>60%) and had seen a significant increase in plantation forestry over the last 10-15 years. The plantation history was estimated using the best available data, including an analysis of plantation data supplied by Green Triangle plantation growers as well as data from miscellaneous sources such as aerial photography and vegetation cover data. The majority of plantations in the Darlot Creek (<15% catchment) and Eumeralla River (<15% catchment) catchments were established in 2000-2005, while in the Crawford River (~30% catchment) small areas of radiata pine plantation were established between 1960-1970 and blue gum plantations were established after 1995.

The potential impacts of plantation forests on streamflow were investigated using the Catchment Analysis Tool (CAT, DEPI Victoria). The CAT was selected to investigate plantation forestry, due to its ability to incorporate land use change history over time within a spatial context to predict catchment water use and streamflow. In this study two component models, CAT1D and CATNode, were used to link paddock-scale land use, soils, topography and climate data to catchment-scale groundwater systems and streamflow at the gauge. The CATNode model was calibrated using the Plantation History land use layer as the best available history of land use and land use change in the catchment. To investigate whether the inclusion of plantation history improved the prediction of streamflow compared to the Static land use, the calibrated model was re-run using the Static land use layer and the difference in cumulative flow was analysed.

CAT was able to provide an adequate streamflow prediction over time (monthly Coefficient of Efficiency >0.7). In addition the incorporation of timing and pattern of plantation history demonstrated a small, consistent improvement in temporal streamflow predictions in each of the three catchments, with the results demonstrating a delayed pattern (4-5 years) in streamflow response consistent with the timing and pattern of plantation history. Due to the hydrological complexity of landscapes, the impact on streamflow of future plantation expansion will vary across the landscape; CAT presents a valuable tool for investigating the potential impacts of future plantations.

Keywords: *Forestry, Afforestation, CAT, Water yield, Land use change*

Simulating the impact of extreme heat and frost events on wheat production: the first steps

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Abstract: In Australia, wheat production occurs on over 13 million hectares, producing on average 19 million tonnes of wheat per year. Extreme weather events, such as frost and heat shock (short period of very high temperatures (>35°C)), can reduce wheat yields and represent a substantial management challenge. Damage due to frost and heat shock is greatest at ear emergence and around anthesis causing significant reductions in grain number and yield potential. Heat shock can also significantly reduce grain weight during the grain fill period when the risk of heat is greatest.

Paddock-based crop models currently used to simulate crop production do not adequately account for the impact of extreme weather events such as frost and heat shock on yield components. While it is feasible to construct crop modules which capture this impact by extreme short term weather events, we felt it was important to quantify the frequency and spatial extent of the problem. This was important in determining whether the frequency and extent of potential grain losses from extreme weather events warranted the inclusion of added parameter input complexity within crop models. By taking into account the interactions between climate and crop phenology we were able to categorise areas as frequently affected by either frost or heat shock, those areas affected by both heat and frost and finally those areas which were rarely affected by either. Strategies to reduce the risks of extreme events will potentially be different for each of these regions.

This paper investigates the spatial extent of where there is potential for improvements to the grains industry by having crop models which account for extreme heat and frost impacts linked to the key phenological crop stages. By incorporating phenological crop development, initiated by the autumn-break our analysis has established the actual frequency of overlap between extreme events and key phenological stages each year. This is important in determining the value of developing heat and frost modules to incorporate into crop models. To quantify the risk frequency of extreme heat and frost events across southern Australia's wheat growing regions the Catchment Analysis Tool (CAT, DEPI Victoria) was used. The study area (ca. 68 million hectares) incorporated agricultural land within the 200-1000 mm annual rainfall region and was significantly larger than the actual area sown to wheat annually. Two key periods were considered (a) a two week period centered on anthesis (50% of crop flowering) and (b) grain fill, for mid-season wheat variety using 50 years historical climate data.

Based on our assumption of sowing at the autumn break, the occurrence of frost around anthesis and extreme heat during the grain fill period were important both in terms of frequency of occurrence and spatial area affected. Across the study region approximately 27% (ca. 18.5 million hectares) had a greater than 1:3 chance of both frost and extreme heat occurring at key crop phenological times, while 29% of the study area was generally affected by heat only during grain fill and 32% was generally affect by frost only. Additionally 12% (ca. 8 million hectares) had a less than 1:3 frequency of both frost and extreme heat occurring at key crop phenological times.

Keywords: *CAT, phenology, heat waves, cropping*

Potential for future growth in lamb supply from sheep and beef farming systems in Hawke's Bay, New Zealand

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Abstract: The potential for expanding irrigation on the Ruataniwha Plains (Hawke's Bay, New Zealand) through proposed in-river water storage creates new land use options, including lamb finishing. It has been estimated that 500,000 additional lambs could be finished each year from 10,000 of the 20,000+ ha within the proposed irrigation scheme. Sheep and beef farming is the predominant land use, covering 785,000 ha or 60% of the Hawke's Bay Region, which has a predominantly summer-dry environment. The majority of sheep and beef farms are found in hill and steep-land, landscapes some vulnerable to landslides and associated soil erosion and sediment loss during rain storm events.

There are calls to transition land use on the most vulnerable land to landslides to protective woody vegetation, including production forestry or space planted trees. Using a novel approach of linking spatial land resource information to regional economic data, we modelled lamb production under scenarios of land use change, hierarchically at farm and regional scales. Our results suggest that increases in lamb production on the high-production capability land on-farm, achievable through increases in efficiency and intensification, would offset reductions in production due to tree planting. Further, the additional store lamb demand for finishing created by the proposed water storage project, through the development of 10,000 ha of intensive lamb finishing, could be met by ongoing productivity gains from sheep and beef operations in hill land. Our spatially linked approach to analysis contrasts against a status-quo of regional-scale averages. This offers industry and policy-makers greater confidence in appraising investment options and policy options for managing land use and land use change, respectively.

Keywords: *Land use change, irrigation, Ruataniwha Water Storage scheme*

A simple carbon offset scenario tool (COST) for assessing dairy farm abatement options

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Abstract: The dairy Carbon Offset Scenario Tool (COST) was developed to explore the influence of various abatement strategies on greenhouse gas (GHG) emissions for Australian dairy farms. COST is a static spreadsheet-based tool that uses Australian GHG inventory methodologies, algorithms and emission factors to estimate carbon dioxide, methane and nitrous oxide emissions of a dairy farm system. One of the key differences between COST and other inventory-based dairy GHG emissions calculators is the ability to explore the effect of reducing total farm emissions on farm income, assuming the strategy was compliant with Kyoto rules for carbon offsets.

COST provides ten abatement strategies across the four broad theme areas of diet manipulation, herd and breeding management, feedbase management and waste management. Each abatement strategy contains four sections; two sections for data entry (baseline farm data specific to the strategy explored and strategy-specific variables) and two sections for results (milk production results and GHG/economic-related results). Key sensitive variables for each strategy, identified from prior research, and prices for milk production and carbon offsets are adjusted through up/down buttons, which allows users to quickly explore the impact of these variables on farm emissions and profitability. For example, if the cost to implement an abatement strategy is doubled, what carbon offset income would be required to negate this additional cost? Results are presented as changes in carbon offset income, strategy implementation cost, additional milk production income and net farm income on a per annum and on a per GHG emissions intensity of milk production basis.

COST currently contains a comprehensive range of strategies for GHG abatement, although some strategies are still in development. As new technologies or farm management practices leading to a reduction in GHG emission become available, these too will be incorporated into COST. To date, two dairy-specific abatement methodologies have been legislated as part of Australia's commitment to reducing on-farm GHG emissions through it's the carbon offset scheme, the Carbon Farming Initiative (CFI) and are incorporated into COST. These are the 'Destruction of methane generated from dairy manure in covered anaerobic ponds' and the 'Methodology for reducing greenhouse gas emissions in milking cows through feeding dietary additives'.

As an example, we explored the mitigation option *Replace supplements with a source of dietary fats* (reflecting the second above-mentioned CFI legislated abatement strategy) as feeding a diet higher in dietary fats has been shown to reduce enteric methane emissions per unit of feed intake. A 400 milking herd was fed a baseline diet of 2.6% dietary fat. By replacing grain with hominy meal, at a rate of 5.0 kg dry matter/ cow per day for 90 days during the 3 summer months, the summer diet fat concentration was increased to 6.4%. Enteric methane emissions were reduced by 40 tonnes of carbon dioxide equivalents (t CO_2e) per annum for the farm. Waste methane and nitrous oxide emissions were also reduced by 0.5 and 1.6 t CO_2e/annum, respectively. However, as reductions from these two sources of GHG emissions do not qualify for payment with this CFI methodology, their reduction could not be included as an offset income. At a carbon price of \$20/ t CO_2e, the reduction in enteric methane emissions was valued at \$800/farm. The implementation cost of replacing grain with hominy was valued at \$18,000/farm due to the hominy meal costing an additional \$100/t dry matter compared to the grain. However, the additional milk production achieved due to the higher energy concentration of the diet resulted in an additional 70,200 litres and based on a summer milk price of \$0.38/ litre, this equated to an additional income from milk valued at \$26,676/farm. The overall result was a net increase in farm profit of \$9,476/farm when paid on a reduction in total GHG emissions. COST can quickly allow users to ascertain the level of GHG emission reduction possible with various mitigation options and explore the sensitivity of key variables on GHG emissions and farm profitability.

Keywords: *Carbon offsets, dairy, greenhouse gas emissions, methane, nitrous oxide*

Stochastic growth models for analyzing crustacean data

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Abstract: The contemporary methodology for growth models of organisms is based on continuous trajectories and thus it hinders us from modelling stepwise growth in crustacean populations. Growth models for fish are normally assumed to follow a continuous function, but a different type of model is needed for crustacean growth. Crustaceans must moult in order for them to grow. The growth of crustaceans is a discontinuous process due to the periodical shedding of the exoskeleton in moulting.

The stepwise growth of crustaceans through the moulting process makes the growth estimation more complex. Stochastic approaches can be used to model discontinuous growth or what are commonly known as "jumps" (Figure 1). However, in stochastic growth model we need to ensure that the stochastic growth model results in only positive jumps. In view of this, we will introduce a subordinator that is a special case of a Levy process.

A subordinator is a non-decreasing Levy process, that will assist in modelling crustacean growth for better understanding of the individual variability and stochasticity in moulting periods and increments. We develop the estimation methods for parameter estimation and illustrate them with the help of a dataset from laboratory experiments. The motivational dataset is from the ornate rock lobster, Panulirus ornatus, which can be found between Australia and Papua New Guinea.

Due to the presence of sex effects on the growth (Munday et al., 2004), we estimate the growth parameters separately for each sex. Since all hard parts are shed too often, the exact age determination of a lobster can be challenging. However, the growth parameters for the aforementioned moult processes from tank data being able to estimate through: (i) inter-moult periods, and (ii) moult increment.

We will attempt to derive a joint density, which is made up of two functions: one for moult increments and the other for time intervals between moults. We claim these functions are conditionally independent given pre-moult length and the inter-moult periods. The variables moult increments and inter-moult periods are said to be independent because of the Markov property or conditional probability. Hence, the parameters in each function can be estimated separately. Subsequently, we integrate both of the functions through a Monte Carlo method. We can therefore obtain a population mean for crustacean growth (e.g. red curve in Figure 1).

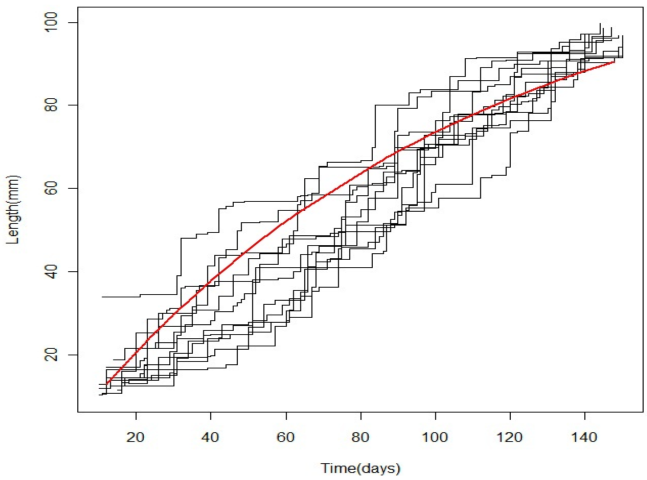

Figure 1: Growth trajectories of crustaceans

Keywords: *Subordinator, discontinuous growth trajectories, moulting*

Optimal Selection of Whey Processing Facilities and Technology

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Abstract: A large proportion of cheese makers in many countries is made up of small enterprises that use less than 25,000 litres of milk per day. Currently, whey, a by-product of cheese making, goes mostly to waste as a highly contaminating effluent or to animal feed because small manufacturers do not have the capacity to preserve it to consistent quality levels. The optimisation model we present aims at achieving better whey utilisation by selecting a processing site from a cluster of cheese makers, suggesting transportation routes, and selecting among a number of technological alternatives for developing products from underutilised whey. The backbone of the model is a network design/facility location problem, with additional constraints that enable optimal technology selection for whey processing at the selected sites. We present preliminary results for a cluster of Victorian cheese makers to prove the feasibility of the approach. The model will economically assess the feasibility of developing distribution chains of underutilised whey in selected country regions.

Keywords: *Facility Location*, *Network design*, *Dairy supply chain*, *Technology selection*, *Mixed-integer linear programming*

Climate change adaptation-mitigation tradeoffs in the southern Australian livestock industry: GHG emissions

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Abstract: The trade-offs between farm system production and profitability, adaptation to climate change and mitigation of greenhouse gas (GHG) emissions are associated with complex interactions. The GHG mitigation consequences of effective adaptations should be taken into account when including them in mitigation policies. In this paper, we present the results of 2 modelling studies of climate change adaptation x mitigation interactions in southern Australian broadacre livestock production: (a) case studies of adapting to climate change by increasing soil fertility at 2 locations that examine the effects on farm-level GHG balances, and (b) an examination how systematic combinations of adaptations (grassland management and animal genetic improvement) might affect future methane (CH_4) emissions across the whole of southern Australia (33.25 Mha). We used the AusFarm model to simulate the effects of climate change under the SRES A2 scenario in 2030.

Merino ewe grazing systems were modelled at 2 locations (Lake Grace, WA and Wellington, NSW) under historical climate and climates projected for 2030. The effects of adapting to climate change by increasing soil fertility by adding phosphorus (P) on system productivity, profitability, N_2O emissions, enteric CH_4 emissions, and changes in soil carbon stocks were estimated. The negative impacts of climate change on productivity were reduced by achieving higher soil fertility, so increasing profitability at 2030. CH_4 emissions declined under 2030 climate owing to lower sustainable stocking rates, but the reduction was smaller when soil fertility was increased. Soil C stocks were predicted to decrease under 2030 climate due to a decrease in net primary productivity of the pasture. Increasing soil fertility was predicted to cause little change in soil carbon stocks, because its main effect was to increase NPP consumed by livestock instead of NPP left to be incorporated into the soil. An increase in N_2O emissions under 2030 climate can be related to changes in rainfall regime. Increased soil fertility by P could slightly reduce this increase. Higher soil P fertility decreased N_2O emissions compared with no adaptation by 7% at Lake Grace and 25% at Wellington.

CH_4 is the second most important anthropogenic GHG. Ruminants (2.4 Gt CO2-eq yr^{-1}) are the largest source of CH_4 emissions. By modelling 5 livestock enterprises at 25 representative locations, we estimated an area-average ruminant CH_4 emission rate of 70 kg ha^{-1} yr^{-1} during the historical period, which is consistent with previous estimates. By decreasing optimal sustainable stocking rates (OSSR), climate change impacts were projected to decrease ruminant CH_4 emissions to 55, 51, and 42 kg ha^{-1} yr^{-1} in 2030, 2050, and 2070, respectively. Ruminant CH_4 emissions under the most profitable systemic adaptation were estimated to vary among sites, depending mainly on OSSR. If the most profitable adaptations were fully adopted, average ruminant CH_4 emissions were estimated to increase to 84 kg ha^{-1} yr^{-1} in 2030, 83 kg ha^{-1} yr^{-1} in 2050, and 75 kg ha^{-1} yr^{-1} in 2070.

Across regions and averaging among enterprises, a linear relationship was found between CH_4 emissions (kg ha^{-1}) and profit (A$ ha^{-1}). A linear relationship was predicted between CH_4 emission and meat production. In 2050, the most profitable combination of adaptations will result in CH_4 emission changes that range between factors of -0.82 and +1.08 relative to the reference period. In addition, CH_4 emissions will reach an intensity of 0.26 kg ha^{-1} yr^{-1} (6.5 CO_2-eq kg ha^{-1} yr^{-1}) for each A$1 of profit and 0.99 kg ha^{-1} yr^{-1} (24.9 CO_2-eq kg ha^{-1} yr^{-1}) for 1 kg of meat production. Across regions and averaging among enterprises, changes in the CH_4 emissions for the most profitable combinations had a logarithmic relationship with changes in profitability (e.g. for 2050: $\Delta CH_4 = 0.207 \ln(\Delta \text{profit}) - 0.326$, $R^2=0.63$).

Ruminant CH_4 emissions will depend on animal numbers (i.e. stocking rates) that, in turn, will be controlled by adaptation intensity. Greater intensification and ruminant CH_4 emission are likely to occur, because increasing demand of meat has been projected for the future and there is capacity for higher and profitable production to respond this demand. Future food market projections have shown such a great demand even under price effects.

Keywords: *Grazing systems, climate change, nitrous oxide, methane, soil carbon*

Does increasing ewe fecundity reduce whole-farm greenhouse gas emissions intensities?

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Abstract: Livestock are by far the greatest contributor to Australian agricultural greenhouse gas (GHG) emissions and are projected to account for 72% of total agricultural emissions by 2020. This necessitates the development of GHG mitigation strategies from the livestock sector. Currently there are many research streams investigating the efficacy of GHG mitigation technologies, though most are at the individual animal level. Here we examine the effect of a promising animal-scale intervention - increasing ewe fecundity - on GHG emissions at the whole farm scale. This approach accounts for seasonal climatic influences on farm productivity and the dynamic interactions between variables.

The study used a biophysical model and was based on real data from a property in south-eastern Australia that currently runs a self-replacing prime lamb enterprise. The breeding flock was a composite cross-bred genotype segregating for the *FecB* gene (after the 'fecundity Booroola' trait observed in Australian Merinos), with typical lambing rates of 150-200% lambs per ewe. Lambs were born in mid-winter (July) and were weaned and sold at 18 weeks of age at the beginning of summer (December). Livestock continuously grazed pastures of phalaris, cocksfoot and subterranean clover and were supplied with barley grain as supplementary feed in seasons when pasture biomass availability was low. Biophysical variables including pasture phenology and flock dynamics were simulated on a daily time-step using the model GrassGro with historical weather data from 1970 to 2012. Whole farm GHG emissions were computed with GrassGro outputs and methodology from the Australian National Greenhouse Accounts Inventory (DCCEE, 2012).

Increasing ewe fecundity from 1.0 lamb per ewe at birth (equivalent to scanning rates at pregnancy of 80% of ewes with single lambs, 17% with twins and 3% empty) to 1.5 (scanning rates of 20% ewes with singles, 51% with twins, 26% with triplets and 3% empty as observed at the property) reduced mean emissions intensity from 9.3 to 7.3 t CO_2-equivalents/t animal product and GHG emissions per animal sold by 32%. Increasing fecundity reduced average lamb sale liveweight from 42 to 40 kg, but this was offset by an increase in annual sheep sales from 8 to 12 head/ha and an increase in average annual meat production from 410 to 540 kg liveweight/ha.

A key benefit associated with increasing sheep fecundity is the ability to increase enterprise productivity whilst remaining environmentally sustainable. For the same long-term average annual stocking rate as an enterprise running genotypes with lower fecundity, it was shown that genotypes with high fecundity such as those on the property could either increase meat and wool productivity from 449 to 571 kg/ha (clean fleece weight plus liveweight at sale) with little change in net GHG emissions, or reduce net GHG emissions from 4.1 to 3.2 t CO_2-equivalents/ha for similar average annual farm productivity. In either case, GHG emissions intensity was reduced by about 2.1 t CO_2-equivalents/t animal product.

From a methodological perspective, this study revealed that differences in computing the relative effect of increased fecundity on total farm production, GHG emissions or emissions intensity either *within* or *across* years were relatively small. For example, the mean difference in emissions intensity of an enterprise obtaining 1.5 lambs per ewe relative to an enterprise obtaining 1.0 lamb per ewe computed within years was -25%, whereas the relative difference in mean emissions intensity across years was -27%. Such findings justify the traditional approach of previous GHG mitigation studies which compare differences (e.g. abatement potential) between values averaged across multiple-year simulation runs, as opposed to the method of computing the differences between intervention strategies within years then comparing the average difference.

Keywords: *Biophysical model, CFI, fecundity, grazing, greenhouse gas emissions, livestock*

High-resolution continental scale modelling of Australian wheat yield; biophysical and management drivers

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Abstract: Production of cereal crops in Australia occurs in a specific envelope of biophysical attributes leading to suitable and non-suitable regions for cereal production. The geographic extent that this envelope encompasses is vast and varied. However, understanding the optimal conditions can only really be achieved through spatially and agronomically detailed studies of local biophysical attributes. Computational limitations and data burdens have limited the scope and resolution of studies in the past. We employed high performance grid computing and parallel programming to operationalise the Agricultural Production Simulation model (APSIM). We then simulate wheat production potential over 110 years across 180,000,000ha of arable land in Australia and statistically evaluate the results to determine the key drivers.

Analysis units were derived through a cluster evaluation of the primary climate and soil characteristics across an extended Australian cropping range. APSIM was used to generate simulated wheat production outputs for all locations over 110 years with 325 combinations of fertilization, tillage and residue treatments. Biophysical and management drivers were then examined for correlation using Spearman's Rho. Examinations of 3 management, 7 climate and 7 soil parameters (at 5 different soil depths) provided an indication of the strength and direction of each of these drivers on wheat yield. Based on the strength of the correlation, Nitrogen (N), Effective Rainfall in the Sowing to Harvest period (ER), Maximum Temperature in the Sowing to Harvest period (MTSH) and soil Water Holding Capacity (WHC) were found to be the key drivers of national scale wheat yield in Australia. Outputs were statistically validated against empirical data for similar fertilization, climate and soil characteristics in selected locations.

Results indicate that crop production varies considerably in space, time and in response to management action. Of the biophysical factors used in the model, ER between sowing and harvest exhibited a strong positive correlation with yield. This parameter also expressed the strongest correlation in any direction, at 0.64. Accumulated rain also returned a strong positive correlation with yield although it was considered a similar parameter to ER. Additionally the MTSH exhibited the strongest negative correlation with yield (-0.34). The length of the growing season also demonstrated a positive correlation with yield (0.32). Fertilizer application was by far the management driver with the strongest correlation with yield at (0.53) whilst both residue removal and residue incorporation expressed weak negative (-0.04) and positive (0.02) correlations with yield respectively. No soil parameters demonstrated strong correlations with yield at any depth in the soil profile.

Results indicate that crop production varies considerably in space, time and in response to management action. Biophysical influences such as climate and soil exert an influence on yields with effective rainfall the key driver of production. An opportunity for farm managers to improve crop yields through careful management of fertilizer application in a small window where the marginal benefits of application change rapidly with other biophysical characteristics. These locations and timings require careful management so as to maximise yield without wasting resources. In all other times and locations the need for careful management is much less important as the relationships are largely unresponsive to one another. Like any study across large heterogeneous landscapes, considerable variations occur in the complex relationships between management and biophysical attributes. Understanding these complex relationships at a national scale is fundamental to sound future planning for issues of national importance such as climate change, soil carbon management and food security.

Keywords: *Agricultural Production, Agricultural Production Simulation model (APSIM), Spatial*

An interdisciplinary framework of limits and barriers to agricultural climate change adaptation

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Abstract: Agriculture is one of the key economic sectors that are most vulnerable to the impacts of climate change (Pearson et al., 2011). Changes in (variability of) temperature, rainfall and the concentration of CO_2 in the atmosphere will directly affect crop and livestock productivity. Although farmers may be particularly knowledgeable in dealing with climate variability, the magnitude of climate change impacts on farming might turn out to go beyond anything that farmers have previously experienced (Stokes and Howden, 2010). This means that adaptive actions are likely to be important to protect farmers' livelihoods from the impacts of unavoidable climate change.

There are, however, various limits (absolute obstacles) and barriers (mutable obstacles) to climate change adaptation. The importance of understanding these barriers and limits to support a sustainable and resilient agricultural sector is increasingly acknowledged by academic researchers and government agencies (e.g., Adger et al., 2009; European Commission 2007; Stokes and Howden, 2010; US EPA, 2012). With this increased focus on limits and barriers to adaptation, has come a heightened awareness that the complex, multifaceted nature of climate change requires interdisciplinary research to improve our understanding of obstacles. Unfortunately, the success of inter-disciplinary projects is often hindered by a lack of common definition of limits and barriers to climate change adaptation. In this study, we develop a conceptual model that integrates different understandings of limits and barriers to agricultural climate change adaptation.

Following Pearson *et al.* (2011), we based our conceptual model on the academic and grey literature as well as expert interviews. The model shows how 'adaptive capacity' and 'willingness to adopt' determine whether a farmer may take adaptive action. Factors that can present limits or barriers to adaptation include biophysical, technological, and socio-economic factors, as well as farmers' personal characteristics and the socio-cultural context in which the farmer operates.

Consultations with experts from various disciplinary backgrounds informed the model development process. Several epistemological challenges were encountered during the study, with disciplinary experts defining limits and barriers to adaptation in different ways. For example, agronomists, economists and biophysical scientists explained that social barriers to adaptive capacity were related to farmers' individual business management skills. Social scientists, on the other hand, used the term social barriers also to indicate that cultural beliefs and values affect a farmers' flexibility or ability to learn new practices. Other epistemological challenges arose when discussing economic limits and barriers. While most experts agreed that adaptation should be aimed at welfare maximisation, different disciplines used variable descriptions of 'welfare'. Many scientists understand economic welfare as a concept that is solely concerned with financial (directly tangible) costs and benefits. Economists in the project, however, incorporated tangible and intangible (non-marketed) values in their definition of economic welfare. It is recommended that future interdisciplinary research between biophysical, economic and social scientists carefully discusses and defines how terms considered in the study are understood across disciplines. The integrated framework developed in the present study provides a guiding tool for such future integrated projects, to help overcome the epistemological challenges that are typically encountered in multi-disciplinary research.

Keywords: *Adaptation, conceptual modelling, expert opinion, epistemology, interdisciplinary research.*

Modelling trimmed fat from commercial primal cuts

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Abstract: A number of studies over the last five years have been conducted to determine total body fat (kg) in cattle and subsequently retail beef yield. Abattoirs are not consistent in the quantity of fat they trim off commercial bone-out primal cuts (e.g., striploin, cube roll etc.). The trimming of fat on a single primal by different abattoirs can range from 3 to 7 mm. If a relationship between mm of fat trimmed and kg of fat removed from primal cuts was developed then total body fat (kg) from commercial slaughters could then be estimated. The estimate of total body fat would assist in establishing a method for determining denuded yield which would then be used as a national standard for describing retail beef yield independent of abattoir. The estimate of retail beef yield would then be implemented into the BeefSpecs calculator.

The objective of this study was to develop a relationship between trim (mm) and kg of fat removed. Images from X-ray computed tomography (CT) scans of 8 primal cuts from 10 Angus steers were manipulated to generate CT scan images for trims ranging from 0 to 15 mm. These images were analysed to determine the weights of fat and muscle in each primal, which were subsequently converted to ratios. Eleven non-linear growth functions were fitted to the generated data and compared to assess their ability to accurately predict the trimmed muscle ratio. The Schnute growth function was identified as the best fit model with the lowest *AICc* (corrected Akaike's Information Criterion) (*AICc* = -480.879, adjusted R^2 = 0.945, *RMSE* = 0.023). The proposed model (and parameter estimates) can be used to estimate the kg of fat removed and therefore aid in the estimation of retail beef yield.

Keywords: *CT scanning, images, retail beef yield, growth functions*

Temperature Increase and Cotton Crop Phenology

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Abstract: The daily outputs of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Conformal Cubic Atmospheric Model driven by four general circulation models (GCMs) were used by a stochastic weather generator, LARS-WG, to construct local climate change scenarios at nine key cotton production areas in eastern Australia. These climate change scenarios were then linked to daily temperature-driven models of cotton phenology (the CSIRO Cotton Day Degree calculator and the Last Effective Flower tools) to examine the magnitude of the effects of increased temperature on the initiation and duration of key crop phenophases and on the occurrence of heat stress (hot days ≥ 35°C maximum) and cold shocks (≤ 11°C minimum) during the growing season. The results show that when using 1 Oct. sowing (1) the timing of emergence, 1st square (flower bud), 1st flower and 1st open boll advanced 1~9, 4~13, 5~14, 8~16 days respectively for the period centred on 2030 compared to the period centred on 1990; (2) when crops were planted 10 days earlier, emergence advanced more in most of the locations while other phenological events changed only slightly (approximately 1 day) in comparison with 1st. Oct. sowing; when crops were planted 10 days later all these events generally were delayed (approximately 1.5 days) in comparison with 1st Oct. sowing depending on locations; (3) the timing of the last effective square, last effective flower and last harvestable boll were delayed 7~12, 6~9 and 3~9 days respectively across locations and GCMs; and (4) combining the effects of an earlier time of first square and a later last effective square potentially increased the time for new fruit (squares) to be produced by up to two to three weeks. This analysis highlights the challenges associated with temperature with future climate change for future cotton production in Australia. Future research will be directed to assess the combined effects of changes in temperature, rainfall and atmospheric CO_2 concentration on cotton water use, water use efficiency, cotton lint yield, fibre quality (i.e. micronaire and fibre length); evaluate the effectiveness of a range of plant-based and management-based adaptation options in dealing with climate change risks; and quantify the cost and benefits of identified effective adaptation options, especially with the use of high yielding transgenic cotton with early high fruit loads in Australian high yielding (>2000kg lint /ha) irrigated systems.

Keywords: *temperature increase, cotton phenology, heat stress, cold shock*

Use of human urine as a fertilizer for corn, potato, and soybean: A case-study analysis using a reactive model

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Abstract: With the population increasing worldwide and the fast expansion of urban areas, there is an escalating exploitation of natural resources and a large, localized production of waste. The production and provision of food is increasingly consuming land and water, requiring a large use of fertilizers. At the same time, most of the existing waste-water treatment plants in cities are not energetically efficient and are not designed to retrieve and re-use a large proportion of nutrients contained in waste-water. There is thus a compelling need to find alternative uses of waste products to transform them in possible resources. Human liquid waste, available in large quantities in urban areas, might be a good candidate to replace mineral fertilizers.

Human urine contains considerable amounts of primary crop nutrients, *i.e.*, nitrogen (N), phosphorous (P) and potassium (K), and secondary nutrients, including sulphur (S), calcium (Ca) and Magnesium (Mg). Trials of human urine applications as an organic fertilizer in small-scale agricultural plots have shown the potential to match the crop yield quantity and quality commonly achieved with mineral fertilizers.

Despite these preliminary studies, knowledge about the performance of urine as an effective fertilizer is still limited. Human urine is a mixture of more than 200 compounds including electrolytes, vitamins, hormones, and other organic and inorganic compounds. About 70 compounds have concentration higher than 10 mg/L, and correspond to a mass of about 36.8 g/L, 8.12 g/L of which is N. To date, there is no understanding of the chemical and biological breakdown processes that release end products easily accessible to roots, such as NH_4^+, PO_4^{-3}, K^+, SO_4^{-2}, Ca^{+2} and Mg^{+2} ions. Likewise, mechanistic models to help plan fertilization applications to achieve targeted crop yields are not available.

This work thus uses a reaction network of the decomposition pathways of human urine in soils to estimate the release rate of ionic end-products required by plants. The model permits the assessment of the rate of urine applications required to meet the N, P, K, S, Ca and Mg uptake demand in extensive agriculture. We present here the chain of reactions implemented in the model and preliminary results for application in extensive cultivation of corn, potato, and soybean, which are among the most cultivated crops worldwide. The presentation focuses on primary and secondary nutrient uptake supplied by amendments of human urine in various scenarios lasting for 120 days, corresponding to a typical growing season; we considered 3 impulsive applications of human urine at 0, 35, and 80 days at fertilization rates of 0.01, 0.05, and 0.1 L m^{-2} with a dilution ratio of 0.1 (1 part of human urine and 9 parts of water).

Results showed that soybean was the only crop to receive the required nutrient amounts with urine applications; conversely, corn and potato plants received less than 70% of the required primary and secondary nutrients even for the largest fertilization rates tested here.

Although results are preliminary, they suggest that human urine can be effectively used in extensive agriculture to reduce the production and use of synthetic mineral fertilizer. It is possible to envision that a reactive model such as the one presented here may be used to optimized the timing and rate of urine applications. Thus, it is presumable that the effectiveness of urine fertilization may increase beyond the values reported here. Future work should focus on optimization scheme for specific crops and environmental conditions. In addition, the reactive model should be included in a numerical framework to account for transport of aquesous and gaseous species along a soil column.

Keywords: *Human Urine, Organic Fertilizer, Nutrients, Crops*

Simulation study of low and high productivity landscapes for lamb production: comparison of two whole-farm systems

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Abstract: In collaboration with Meat and Livestock Australia and the Australian Government's Climate Change Research Program, the national "Reducing Livestock Emissions Program" (RELP) established a 36-ha 'Trevenna' sheep production demonstration site in Armidale on the Northern Tablelands of New South Wales to provide estimates of on-farm carbon. It was a collaborative project between NSW Department of Primary Industries and the University of New England (UNE). In brief, a replicated study over two years was established to compare animal productivity and emissions of low (3.7 DSE/ha) and high (6.7 DSE/ha) productivity landscapes. Seven soil samples and an EM38 soil map (characterization of the soil diversity) were used to characterize the two landscapes and to block each landscape into three classes where each class had three paddocks (i.e. eighteen paddocks; nine low and nine high productivity landscapes). Actual monthly pasture (green and dead DM availability) and regular production data (liveweight (LW) gain, fat score, fecundity, wool and lamb carcass weights at slaughter) were collected.

A simulation study using both GrassGro and SGS across 50 years of variable climate (1961-2011) was conducted. The results from this study including the observed values and the simulated values for one year are reported. Across the 50 year simulation lamb intensity (kg CO_2e/kg lamb LW) using GrassGro was significantly different ($P < 0.001$) for low (9.71 kg CO_2e/kg lamb LW) versus high (8.04 kg CO_2e/kg lamb LW) productivity landscapes and using SGS was significantly different ($P < 0.01$) for low (4.86 kg CO_2e/kg lamb LW) versus high (4.06 kg CO_2e/kg lamb LW) productivity landscapes.

Keywords: *Lamb intensity, methane, variable climate*

Production of a map of greenhouse gas emissions and energy use from Australian agriculture

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Abstract: The agriculture and forestry sector accounts for approximately 24% of total greenhouse gas (GHG) emissions in Australia. Over the years researchers have produced new knowledge about agricultural GHG emissions and energy use patterns and opportunities to decrease them, albeit in small-scale studies or large-scale ones with coarse resolution. Linking the multiple, diverse and rich datasets around agricultural production in Australia into one dataset that allows for an estimate of GHG emissions and energy use related to agriculture at a national scale and high resolution has not been done before.

The approach we describe here is based upon a link between operational data sourced from gross margin (GM) handbooks and life cycle assessment (LCA) process data. We have collected and processed these datasets to produce a comprehensive database of typical agricultural operations covering 72 commodities grown in 42 regions across Australia. We have also created a system that estimates the GHG emission and energy use patterns of the aforementioned commodities using the best available LCA process data.

To capture GHG emissions of non-domestically produced fertiliser, we queried the United Nations Commodity Trade Statistics Database (COMTRADE) to analyse the fertiliser and pesticide import patterns for Australia between 2000-2010. This analysis determined the average country energy-mix for fertiliser and pesticide manufacturing and allowed linking the associated GHG emissions to Australian agricultural production.

Finally we spatialised agricultural operational data, emissions and energy use at the national scale using the latest Australian Land Use Map (2005/06). Our findings suggest that in 2005/06 greenhouse gas emissions related to Australian agricultural production equate to a total of 95.8 Mt CO_2-e using 75.7 GWh of energy. According to our results 29.4% of these emissions come from sources that were categorised as non-agricultural (e.g. industrial processes or energy use) in the Australian National Greenhouse Gas Inventory (NGGI) 2006. We find that the provision of transparently modeled GHG emissions and having them linked to a spatially explicit component helps identifying new opportunities for emission reduction and facilitates an assessment of their effects. For example, our findings suggest production of ethanol from corn stover and sugarcane bagasse could have avoided 4.37 Mt CO_2-e emissions (4.56% of total) without affecting food production.

Keywords: *Agricultural Systems, GHG Emissions, Energy Use, LCA, GIS*

A conceptual spatial system dynamics (SSD) model for structural changes in grassland farming

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Abstract: Typically, discrete-time agent-based models and cellular automata approaches have been used to model farm structural changes. However, the proposed methodology uniquely considers a cross-disciplinary, continuous System Dynamics (SD) simulation approach to capture temporal dynamics of grasslands farming structure. The SD approach is particularly well suited for participatory modeling and involving stakeholders in the model development and simulation processes.

In order to capture both spatial and temporal dimensions, this paper proposes a Spatial System Dynamics (SSD) approach. This approach is based on the strengths of system dynamics theory and geographical spatial modeling tools. The SSD approach links system dynamics (temporal simulation) and GIS (spatial analysis and visualization) software. For the purpose of this research, farm structural change is defined by the dynamics of farm size and farming intensity. These characteristics are considered in a conceptual SSD environment referred to as the two-farm structural dynamics (2FaSD) model.

Currently the 2FaSD is a conceptual model, whereby physical farm size is considered part of a finite resources competition model. When farms change structure (physical expansion or reduction in farm size; intensification or deintensification of resources) they compete over grassland resources. The competition is driven by farmer preferences, managerial decisions, environmental conditions and economic situation. The 2FaSD model uses the SSD approach, which for this specific application requires a coupling technique to embed Vensim in ArcGIS. The anticipated model output includes a time-series of maps which graphically represent the changes of ownership structures in a two-farm system. This output is intended to provide decision support for agricultural planning and management strategies.

The 2FaSD model is in the early development stage and the next major step is converting the model from causal loop form to an executable stock and flow simulation model. As the model is in its infancy stage, the 2FaSD model only models competition between two farms for the following reasons: ease of implementation, simplicity in concept demonstration and in anticipation of reduced simulation times. We foresee that the current 2FaSD model and methodology may be extended to consider additional farms in the grasslands competition model in the future. The current 2FaSD model structure has been developed based on assumptions specific to the grassland farming industry in Austria, however with minor modifications to the SD system structure, it is possible that the model could be adapted to simulate grassland farm structural changes in other areas of the world.

Keywords: *farm structure, GIS, grassland farming, spatial and temporal modeling, system dynamics*

Renewable electricity generation for energy-autonomous dairy farms, with backup technologies

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Abstract: Electricity provision is a significant and rapidly increasing cost on New Zealand dairy farms. Over and above rapid cost increases, newly established dairy farms (farm conversions) are faced with the very high capital costs for electricity network connection, often totalling several hundred thousand NZ$. Progress with renewable energy technologies such as wind and solar-based electricity generation, and recent advances with covered anaerobic pond biogas systems treating dairy shed effluent, offer options for establishing energy autonomous dairy farms which rely on a combination of these renewable energy resources.

In a recent paper published by the authors, farm energy needs and renewable on-farm energy resource potential was analysed and a conceptual model presented of a generic 600-cow dairy farm aiming for energy autonomy based on a combination of on-farm biogas, solar and wind technologies. The wind and solar potential was evaluated at four New Zealand locations with contrasting climatic conditions and representative of the majority of New Zealand dairy regions. Analysis of weekly farm energy demand indicated that nearly full energy autonomy could be achieved for most of the year with a combination of biogas and solar based generation in conjunction with some further-to-be-established energy storage technologies. The combination of biogas and wind generation alone yielded poorer results. For the combination of biogas and solar, the modelled weekly energy shortfall occurring over 20 weeks of the milking season could be met with a biogas generator back-up fuel such as LPG. Increasing the solar generation capacity to meet the shortfall was found to be impractical as the solar photovoltaic set-up would have to have its capacity quadrupled to meet the shortfall during the worst week of the dairy season. This initial exercise showed that the concept of energy independent dairy farms based on primarily renewable energy resources was feasible in principal.

The purpose of the current work is to extend our previously published work to now include more detailed modelling to determine minimum sizes for energy storage devices (battery, glycol cold storage, hot water storage) for balancing daily and weekly energy demand and supply, and rank and refine charging and discharging priorities of individual system elements.

Our modelling work provides further evidence that the concept of energy independent dairy farms is practical in New Zealand, and showcases the use of biogas technology and practical energy storage systems as an enabler technology for intermittent renewable generation in rural environments. Recently steps have been taken to apply this concept based on modelling into a working New Zealand reality in collaboration with private industry partners.

Keywords: *Wind turbine, Solar, Biogas, Farm conversion, Energy-autonomous dairy farms*

Modelling water and salinity distribution in soil under advance fertigation systems in horticultural crops

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Abstract: New generation irrigation and fertilizer application methods have revolutionised input applications in agriculture, leading to significant savings of scarce resources like water. These systems are highly capital intensive, and apply water at suitable locations, facilitating their maximum uptake by crops. However there is still a need to evaluate these systems for water and salinity dynamics on a long term basis, to further finetune them and come to terms with the high cost involved, and to control the possible deep drainage of water which transports solutes below the root zone endangering the quality of groundwater. But the soil-plant-atmosphere system evaluation in respect of water and salt distribution involves very complex processes which are unable to be managed by experimentation alone. The numerical models offer good opportunity to analyse the complex systems if reliable input parameters are available. In this study, HYDRUS-2D model was used to evaluate the seasonal water balance and salinity distribution in soil under surface drip irrigation of two horticultural crops, almond and mandarin which are widely grown in Australia.

Modelling domain represents the plant spacing of the trees in the field studies. Modelling simulations were carried out on daily basis involving daily input of variable flux equivalent to the depth of irrigation. The daily potential transpiration (T_{pot}) and potential evaporation (E_s) under almond and mandarin trees were estimated by FAO 56 dual crop coefficient method utilizing local weather parameters, soil characteristics and plant estimates. The estimated daily T_{pot} and E_s were then used as daily atmospheric inputs along with rainfall received at the experimental sites. The modelling simulations were carried out for one complete growing season for both crops. The field experiments were equipped with temporal and spatial monitoring of water content and salinity (in mandarin only) distribution following standard procedures. The modelling output on water content and salinity (for mandarin) were compared with the corresponding measured values throughout the growing season. The model was also used for evaluating the impact of water stress and impact of pulsing in irrigation application.

The graphical and statistical comparison of weekly measured and simulated values of moisture content at various depth and distances from dripper revealed fairly good matching. The RMSE values of weekly comparison varied from 0.005 to 0.06 cm^3cm^{-3} in almond and 0.01-0.06 cm^3cm^{-3} in mandarin. The variation of this magnitude generally exists in field measurement of water content. Similarly the comparison between measured and model predicted values of salinity (EC_{sw}) under mandarin also matched well and RMSE ranged between 0.09 to 0.93 dS m^{-1} which is well within the acceptable limit in a complex and highly dynamic soil system. The daily EC_{sw} distribution remained below the threshold salinity values of both crops throughout the growing season. Reducing the irrigation application by 35% (65% ET_C) in almond increased the seasonal salinity substantially. The average increase was about 2.5 fold particularly during the summer season. Hence, the temporal and spatial soil solution salinity distribution (EC_{sw}) obtained from the modelling simulation was very well synchronised with the corresponding moisture regime in the soil under both trees.

The water balance revealed that only 49% of applied water (irrigation and rain) was used by the mandarin tree, allowing a leaching fraction of 34%, while 54-55% water uptake efficiency was recorded in almond under surface drip irrigation. The deep drainage losses in almond accounted for 25% of the total water application. The pulsing of irrigation events produced a similar seasonal water uptake as obtained in continuous irrigation. The modelling simulations revealed that there is a need to further finetune system design and irrigation scheduling so that significant savings of water can be realised.

Keywords: *Modelling, drip irrigation, deep drainage, salinity, almond, mandarin*

Potential for land use change to dairy in Southland, New Zealand: Impact on profitability and emissions to air and water

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Abstract: Southland has witnessed a pronounced change in its agricultural landscape in recent years. Greater profitability of dairy relative to sheep farming has led to a large number of dairy conversions over the last 20 years, with the scope for further substantive conversions into the future. The economic and social benefits have been extensively reported, but less is understood about the environmental impacts associated with this land use change. To investigate the potential effect of land use change from sheep and beef to dairy on economic and environmental outcomes in the Southland region of New Zealand, farm-scale enterprise simulation models were linked with spatially explicit land resource information. By overlaying individual farm parcels with land resource information, land area and topography data for each farm were attained.

Estimated pasture production (PP) for each land use capability (LUC) Class provided indicative data for the modelling exercise on the productive use of the land across the region. The approach provided a method for the expansion of farm scale modelling to a regional scale. A representative DairyNZ Production System 3 was used to investigate the influence of increasing dairy cow numbers and associated inputs at the farm level. A representative sheep and beef farm was also modelled. To account for a dairy support area, used to carry dry cows during the winter, a second step involved the modelling of a larger System 3 dairy farm that included a milking platform area and an adjacent support area. This farm system was considered for regional up-scaling to allow for a more comprehensive capture of nutrient losses and financial outcomes.

Estimates of annual nitrogen (N) leaching values from dairy farms ranged from 21 to 44 kg N/ha, and were higher for farms with greater pasture production potential, due to the greater amount of N cycling and increased number of urine patches from the higher number of livestock numbers carried. Annual N leaching from the sheep and beef farms ranged from 8 to 17 kg N/ha. Annual greenhouse gas (GHG) emissions were also higher from farms with greater productive potential, ranging from 7.1 to 15.4 t CO_2-e/ha for dairy and from 2.1 to 6.9 t CO_2-e/ha for sheep and beef farms. In contrast to leaching, GHG emissions were higher from poorly-drained soils compared with well-drained soils; annual nitrous oxide (N_2O) emissions accounted for 22% and 35% of total GHG emissions from dairy farms on well- and poorly-drained soils, respectively, and up to 40% from sheep and beef farms on poorly-drained soils.

The new dairy farms resulting from conversion would largely fall in an N leaching range of 25 to 31 kg N/ha and have GHG emissions of 7.0 to 10.5 t CO_2-e/ha. Depending on future regional regulations that may be implemented, a large number of potential dairy farms might leach more N than the allowable limit, and mitigation techniques will need to be implemented. A shift in land use from the current 15% of land area under dairying to a potential 46% led to a large increase in regional profit (76%). The environmental impact from this land use change, however, became substantial, with regional nitrate leaching increasing by 34% and GHG emissions by 24%. Conversion of more farms into dairying increased farm profit, N leaching and GHG emissions in the region compared with the current situation. It must be noted, however, that the up-scaling of potential dairy conversion was based on land resources defined by the productive potential of the landscapes found in Southland and that the actual level of conversion could differ substantially if additional or different farming scenarios were tested.

Keywords: *Southland, Dairy, Sheep, Beef, Farmax, Overseer*

What impact do producer measured inputs have on the prediction accuracy of BeefSpecs?

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Abstract: The BeefSpecs fat calculator is a decision support tool created to help the beef industry increase compliance rates with carcass specifications. BeefSpecs combines the predictive powers of animal growth and body compositional models with experimental information relating to animal growth and fatness in response to changes in production environment. To facilitate producer acceptance and adoption, BeefSpecs makes explicit use of inputs that are easily recorded on-farm but still provide effective information to the modelling systems to enable accurate prediction. These inputs include: sex, breed type, initial live weight (kg), frame score, initial P8 fat depth (mm), hormonal growth promotant use, feed type, length of feeding period (days), growth rate (kg/day), and dressing percentage. BeefSpecs provides three outputs that are relevant to commercial production systems, namely final live weight, final subcutaneous rump fat depth (P8 fat), and hot standard carcass weight (HSCW). Most inputs are considered relatively easy to record on-farm but some require a degree of technical expertise (e.g. frame score and estimated P8 fat) or equipment (e.g. scales to record weight or ultrasonic measurement of P8 fat depth).

Although the structure of BeefSpecs represents one of its strengths via the linkage of easily recorded on-farm inputs to producer language, it also represents a potential weakness. The reliance on on-farm inputs dictates that the accuracy of BeefSpecs' predictions is contingent on the accuracy with which these inputs are able to be recorded. The impact inputs have on the prediction accuracy of BeefSpecs has not been reported previously. Sensitivity analysis is used to explore the relationships between information that flows in and out of modelling systems. A sensitivity analysis provides the opportunity to identify and quantify the key interactions present in BeefSpecs and thus provide information concerning where effort should be directed to most accurately record inputs and maximise predictive accuracy.

When investigating the non-linear, and in some cases chaotic, behaviour of models it is critical to measure sensitivities over the whole spectrum of inputs that may be encountered. Many designs have been proposed for testing sensitivity when models are expensive or lengthy to run. However, a complete factorial array of all variables provides the most comprehensive and safest coverage. The simplicity and low computational cost of running BeefSpecs lends itself to a complete factorial sensitivity analysis. The traditional 'one-at-a-time' (OAT) sensitivity analysis was not used because it is fundamentally flawed, as it does not investigate the typically complex and interactive behaviour of biological models. In the OAT approach, the model is configured to an 'average' or baseline scenario, from where each input is tested sequentially making these sensitivities only applicable at the selected baseline scenario.

The sensitivity analysis conducted in this study used a complete factorial array of all BeefSpecs input variables, to provide the most comprehensive coverage. This array of inputs was created by changing each input one variable at a time and required a total of 57,600 model runs. The dominant effects and interactions were identified by conducting an analysis of variance (ANOVA) on the 9-way factorial matrix of inputs.

Frame score was found to have significant impacts on BeefSpecs predictions of final P8 fat depth including errors of up to 2.3 mm P8 fat depth per unit error in frame score. Errors in initial live weight were found to have less impact on P8 fat predictions (e.g. 0.5 mm per 10 kg live weight error). Initial P8 fat depth was also found to have significant impacts on final P8 predictions, particularly at low initial live weights (e.g. up to 1.5 mm P8 fat depth per 1 mm error in initial P8 fat). Analysis of HSCW sensitivity to BeefSpecs inputs found, as would be expected, that HSCW is dependent only on initial live weight, feeding period, growth rate and dressing percentage, and is thus insensitive to other inputs such as frame score and initial P8 fat. These findings indicate that the accuracy of BeefSpecs inputs, particularly frame score and initial P8 fat depth, have critical impacts on prediction accuracy, which in turn impact on the tool's utility and potential adoption rates. These results also provide support for the development of new technologies that will increase the accuracy and ease of recording such inputs in the future.

Keywords: *Sensitivity analysis, beef cattle, prediction error, body composition*

Accuracy of root modeling and its potential impact on simulation of grain yield of wheat

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Abstract: Accurate modeling of root biomass and root distribution of crop plants has become increasingly important to address issues related to carbon sequestration in soil and resource use efficiency of crops under different environmental and management conditions. However, the performance of crop models for simulating crop root system has been rarely tested in many environments due to lack of detailed data caused by the difficulty to measure roots. In this paper, we present detailed measurement data on root biomass and distribution in 0-200cm deep soil profile at key developmental stages of wheat crop at Wuqiao in the North China Plain, and compare them with the root dynamics simulated by the agricultural systems model APSIM. The objectives are to test the model performance for modeling root biomass and distribution, and to investigate the potential impact of errors in root modeling on simulated yield responses under different levels of water and nitrogen supplies through changes in irrigation and nitrogen applications.

The data were collected in two field experiments carried out in the 2003-04 (Exp 1) and 2008-09 (Exp 2) winter wheat growing seasons, each with three irrigation treatments and one fertilizer-N application rate of 158 kg/ha (urea N). Irrigation scheduling included: no irrigation (W0), one time of irrigation ($750 m^3 ha^{-1}$ = 75 mm each time) at jointing stage (W1), two times of irrigation at jointing and flowering stages (W2), three times of irrigation at upstanding (double ridges), booting and start of grain filling stages (W3) and four times of irrigation at upstanding (double ridges), jointing, flowering and start of grain filling stages (W4), all as flood irrigation. Irrigation treatments for Exp 1 were W0, W2 and W4, and for Exp 2 were W0, W1 and W3. All the experiments received 75 mm irrigation applied 5 days before sowing to ensure good emergence. In Exp 1 (2003-04), wheat root samples were collected using a drill (8cm in diameter) down to 200cm depth with a 20 cm interval before winter and at flowering and maturity time. In Exp 2 (2008-09), soil monoliths from a 20 cm (length) × 15 cm (width) area down to 200 cm were extracted, with 20 cm interval for the top two samples, and 40 cm interval for the samples at deeper depth. This was done five times: before winter, and at stages of upstanding, jointing, flowering and maturity. Roots were separated using double-layered sieves (1mm diameter) by washing out the soil with water. In addition, shoot biomass was also measured in each experiment. All plant samples were oven dried at 70°C to constant weight to measure biomass.

APSIM version 7.5 was used to simulate the root and shoot growth of the winter wheat crop against the experimental data. Compared to the measurements from field experiments, APSIM version 7.5 underestimated the rooting front advance and final rooting depth of winter wheat, but overestimated the root biomass and root shoot ratio at maturity by 100-200%. The model also simulated simultaneous increase in both shoot and root biomass with increased irrigation supply, but measurements showed increase only in shoot biomass, not in root biomass. Correction to the simulations of rooting depth and root biomass based on the data led to little impact on simulated shoot biomass and grain yield under conditions of sufficient nitrogen supply, but higher simulated grain yield when nitrogen was deficient. Studies are needed to further investigate APSIM's ability to simulate root growth and its impact on biomass growth and carbon cycling in farming systems across different environments.

Keywords: *root biomass, rooting depth, winter wheat, North China Plain, APSIM*

EXTENDED ABSTRACT ONLY

To weed or not to weed? How Agent Based Models are assisting in weed management and determining optimal and economic benefits of different control strategies.

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Abstract: Whilst economic models can calculate the costs and benefits of different weed management strategies, they have to assume a uniform rate of weed spread that is either under management or spreading without control. They do not take in to consideration the heterogeneous nature of the landscape and the resultant differences in costs and benefits at specific locations. Whilst land managers often report on the effectiveness of control programs in terms of the number of inspections and/or extent of area treated, rarely is there the ability to:

i) Calculate the cost: benefit ratio of programs (the productive value of the area protected over time),
ii) Optimise the strategy by balancing costs with future benefits, or
iii) Allow for adaptive management scenarios

To address these issues we have developed an agent-based weed dispersal model in Net Logo with in-built economic evaluation and management strategies components. A STELLA®-designed plant growth and dispersal model was converted into a spatially explicit Net Logo model with a dynamic interface to allow for “on the fly’ interactions with land managers. We are testing its performance on a real incursion in SE Victoria and will use the validated model to project the spread of a weed over a ten year period. This will compare the costs and benefits of current control measures with a change in strategy to reflect either an increase or decrease in the funding of the weed’s control.

The interactive nature of the model will allow land managers to visualize and calculate the effects of their decisions.

Keywords: *Optimising control strategies, cost: benefit, heterogeneous landscape, interactive, adaptive management*

On quantifying extinction probability from the sighting record

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Abstract: Methods are needed to estimate the probability that a population continues to be extant. Such information is important in underpinning decisions regarding the continuation of an invasive species eradication program, or in deciding whether further searches for a rare species could be warranted. We present and critique a Bayesian method that fully utilizes sighting data and prior knowledge when estimating the detection and survival probabilities of a population, assuming either that these probabilities are constant (the most common default assumption currently) or they vary as simple functions of an exponentially changing population. The method and the influence of the modelling assumptions are illustrated using recently discovered European red fox (*Vulpes vulpes*) carcasses in Tasmania, to make inference on the fate of the underlying process generating the carcasses. Under the very strong assumptions of constant survival and detection probabilities, the probability of population persistence as of 2012 is well defined, but ranges between 6.2% and 13.9% depending on whether the process started in either 2001 or 1999. Under either start time, the most probable year of extinct is 2007. When the survival and detection probabilities are allowed to vary in the simplest ways possible, their estimation (along with fate of the underlying population) become considerably more difficult, and the results much more uncertain. In fact, the extinction probability and timing (if at all) are very poorly informed by the data. We have illustrated how all available detection data and prior knowledge can be utilised when estimating extinction probability. If detection and survival parameters can be safely assumed either constant or declining, then methods can be easily applied to evaluating the success of an invasive species eradication program, or to inferring the fate of a rarely sighted species. We suggest these assumptions represent very strong knowledge that may be hard to justify, and may not hold when analysing sighting records of potentially invasive species subject to eradication attempts. In this situation, methods reliant on these assumptions are potentially illusory in their accuracy, and their use to underpin decision-making somewhat fraught.

Keywords: *Extinction, eradication, inference*

Evaluating the success of pest control programs

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Abstract: Effective invasive species eradication programs require timely provision of information on the population under control. However, estimating the demographic parameters and distribution of an invading population is often challenging, especially when the available information is from a diverse range of sources (e.g. public sightings, camera traps, road kills, DNA forensics, etc.) often collected haphazardly across space and time. There is a need to develop robust techniques for synthesizing such data within operational timeframes to enable pest managers to make the best decisions possible. We illustrate potential methods to estimate the demographic parameters and size of pest population subject to control based using the apparent recent incursion of the red fox (*Vulpes vulpes*) into Tasmania as a case study. A recent study has inferred that the red fox is now widespread in Tasmania as of 2010, based on the extraction of fox DNA from predator scats, which from a biological conservation point of view is rather dire. This inference appears at first glance (mental reckoning) to be at odds with the lack of recent confirmed discoveries of either road-killed foxes—the last of which occurred in 2006, or hunter killed foxes—the most recent in 2001. Here we illustrate how Approximate Bayesian Computation methods they can be applied to such sparse sighting data to make inference on the past, present and future distribution of an invasive species. In doing so, the approach illustrates how mental reckoning of the distribution of an invasive species can be formalised and codified in a transparent and repeatable manner. Importantly, the method is able to inform management of invasive species in real time, and can be applied widely. Based on the pattern of carcass discoveries of foxes in Tasmania, we infer that the population of foxes in Tasmania is most likely extinct, or restricted in distribution and demographically weak as of 2012. It is possible, though unlikely, that that population is widespread. This inference is largely at odds with the inference as of 2010 based on the predator scat survey data. Conditional on the assumption and prior beliefs formalised in the model, we forecast that over the next five years, there is a high probability that either additional fox carcasses will have been discovered or the population will be extinct. Importantly, our results suggest the chances of successfully eradicating the introduced red fox population in Tasmania may be higher than previously thought.

Keywords: *Approximate Bayesian Computation, ABC, inference, eradication, extinction*

When is it optimal to eradicate? A decision tool applied to Siam weed

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Abstract: One of the decision tools most often requested by biosecurity managers is one to help decide whether to attempt eradication, contain, or do nothing in response to a biological invasion. We develop a simple decision tool that can help biosecurity managers understand this decision. The tool is based on an optimization model with three components: a growth curve, a damage curve and a cost curve. Growth is modelled using a logistic equation while damage and cost functions are linear. Information on components of growth, damage and costs is used to calculate the maximum area that should be targeted for eradication, based on minimizing the combined cost of controlling the invasion and the damages caused by the invasion. The optimal steady state, the *switching point*, occurs where the marginal benefit of removing one extra unit of pest is equal to the marginal cost of doing so. It follows that when marginal benefit is greater than marginal cost, the pest should be removed, eventually leading to eradication and when marginal cost is greater than marginal benefits of pest removal, the pest should be allowed to spread.

The tool is applied to the Siam weed (*Chromolaena odorata*) invasion in northern Queensland. Siam weed is native to tropical and subtropical Central and South America. It is a fast growing perennial shrub, often forming dense, tangled thickets and can attain heights up to 20m by scrambling on supporting vegetation. It thrives in disturbed habitats such as pastures, roadsides and riverbanks and can completely dominate the landscape it invades. Siam weed is now widespread throughout Africa, Asia and parts of the western Pacific and is considered one of the world's worst weeds. Siam weed was first detected in Australia in 1994 south of Cairns, and became the target of a national cost-shared eradication programme in 1995.

Control-cost parameters from the Siam weed eradication programme (SWEP) were used in the current application. Specifically, these were the costs of control, search, research and communications and administration. To calculate the total area at risk from Siam weed we assumed that all control operations ceased in 2008 and the weed spread unhindered from all known infestations until a maximum infestation area was reached, in year 25. Invasion damages consisted of impacts on livestock (cattle) through deaths and abortion; damages to horticulture (bananas, citrus, avocado, mango and papaya), agriculture (sugar cane) and forestry; and loss of ecosystem services. Estimates of the value of lost ecosystem services were available from a previous study, and accounted for all the services that will be impacted from Siam weed, including water supply, soil formation, recreation and cultural values.

Results from the deterministic model, implemented as an Excel tool, indicate that, at the switching point, it would cost between \$9 billion and \$13 billion to eradicate Siam weed from between 7 million and 10 million hectares, depending on the specific growth rate. While it may be economically desirable to eradicate areas of up to 10 million hectares, based simply on the benefit-cost approach, budgets for this will not be available hence the importance of developing a budget-constrained version of the model. Results indicate that the area currently invaded, around \$16,500 hectares, could be eradicated at a cost of \$18 million in present-value terms, although this doesn't take into account stochastic disturbances.

As costs of control per hectare increase, the switching point decreases – the area up to which it is optimal to eradicate is reduced. When stochastic environmental disturbances were introduced, by implementing the numerical model in Matlab, this same result occurred. Introducing stochasticity into growth and damage parameters resulted in cautious behavior, where the optimal level of control was intensified when random shocks caused future invasion states to be uncertain.

The switching-point tool is useful in the evaluation of the effects of changes in costs and damages on the optimal solution. This tool could be used by biosecurity managers before considering a full benefit-cost analysis of an invasion to identify the kinds of costs and damages involved and the sorts of budgets that may be required for eradication.

Keywords: *Siam weed, optimization model, eradication, decision tool*

Do locusts seek out greener pastures? A Bayesian hierarchal analysis of the 2010-2011 Victorian Australian plague locust invasion.

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Abstract: Australian Plague Locusts (APL), *Chortoicetes terminifera* (Walker), are a native but serious graminiferous pest of grasslands and cereal crops in eastern and south west Australia causing an estimated $8.9 million loss per annum. In order to control locust plagues, managers need to know where the highest densities of locusts are and what areas are at risk as the adults disperse. Foraging theory indicates that areas with greener grass (higher protein, carbohydrate and water content) should be where adult locusts would preferentially feed. Anecdotal evidence from farmers and the Australian Plague Locust Commission also supports this.

In 2010, Victoria suffered from the largest locust plague since 1976. Over a four month period from Dec – April 2011, 150 sites in 19 localities across central Victoria were monitored weekly and adult APL densities recorded. MODIS satellite Vegetation indices (FPAR, GPP and NDVI) were utilised as an indication of grassland and cereal crop's "greenness".

Bayesian Hierarchal analysis was utilised to model densities of APL at different sites, localities, landuse, time periods and determine the level of correlation to the Vegetation indices.

No evidence was found for increased locust abundance at greener sites. The most important variables were site and location which indicate two scales of spatial correlation. Least important variables in determining abundance were any of the Vegetation indices.

Possible confounding factors are the spatial and temporal resolution of the satellite data and the unusually wet summer contributing to much higher levels of greenness found throughout the study area.

Keywords: *Predicting species presence and abundance, remote sensing, vegetation indices*

Gene expression based Computer Aided diagnostic system for Breast Cancer: A novel biological filter for biomarker detection

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Abstract: Cancer is a complex disease because it makes complex cellular changes. Therefore, microarrays have become a powerful way to analyse cancer and identify what changes are produced within a cell. Through DNA microarrays, it has become possible to look at the expression of thousands of genes in one sample and this is called gene expression profiling. Gene expression profiling is important to capture a set of expressed genes that determines a cell phenotype.

However, analysing microarray data is challenged by the high-dimensionality of the data compared with the number of samples. The aim of this study was to enhance the diagnostic accuracy of Breast Cancer Computer Aided Diagnostic Systems (CADs) that use gene expression profiling of peripheral blood cells, by introducing a novel feature selection method called Bi-biological filter that was further refined by Best First Search with Support Vector Machines SVM (BFS-SVM) to select a small set of the most effective genes predictive of breast cancer. From each patient's gene expression profiles, a gene co-expression network was built and divided into functional groups or clusters using Topological Overlap Matrix (TOM) and Spectral Clustering (SC) in the design of the Bi-Biological filter to obtain the preliminary set of gene markers. BFS-SVM was used to further filter a smaller set of best gene markers, and Artificial Neural Networks (ANN), SVM and Linear Discriminant Analysis (LDA) were used to assess their classification performance. The study used 121 samples – 67 malignant and 54 benign cases as input to for the system. The Bi-biological filter selected 415 genes as mRNA biomarkers and BFS-SVM was able to select just 13 out of 415 genes for classification of breast cancer. ANN was found to be the superior classifier with 93.4% classification accuracy which was a 14% improvement over the past best CAD system developed by Aaroe et al. (2010).

Keywords: *gene expression, mRNA, blood, feature selection, neural networks, breast cancer, Computer Aided Diagnosis, early detection*

Mathematical modelling of p53 basal dynamics and DNA damage response

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Abstract: A gene that plays a crucial role in the regulation of cell life and death is the tumour suppressor gene *p53*, which encodes protein p53. The p53 tumour suppressor protein is regarded as the "guardian of the genome", which is a transcription factor, that activates genes that result in DNA repair, cell cycle arrest, senescence (permanent cell cycle arrest) or apoptosis (programmed cell death) in response to various stress signals that could induce genetic instability. Recent individual cell studies have indicated that p53 activation is highly regulated in response to stress conditions and in unstressed normal proliferating cells. The aim of this research is to investigate the design principles behind the precise regulation of p53 activation. We develop a mathematical model using delay differential equations that incorporate the most recently found molecular interactions and genes regulated by p53, such as p53 activation of MdmX and Wip1, in the core regulation of p53 in normal proliferating cells and cells under DNA damage stress. We model the p53 core regulatory feedback mechanisms that control p53 levels. Experiments have shown that after DNA damage – DNA double-strand breaks (DSBs) – p53 levels show a series of repeated pulses. Whereas in non-stressed conditions with intrinsic DNA damage, one or two spontaneous pulses (basal dynamics) were observed. Figure 1 shows a schematic diagram of the model hypothesis. We found that the core regulatory network consists of ATM, Mdm2, MdmX, Wip1 and p53, and it reproduced simulations consistent with the experimental findings. Our results show that the p53 spontaneous pulses are due to intrinsic DNA double strand breaks in normal proliferating cells. Local parameter sensitivity analysis identified Wip1 as the major component that controlled the period of p53 oscillations. Despite its simplicity, our model is a mechanistic model that presents a dynamic hypothesis of molecular interactions that control p53 activation.

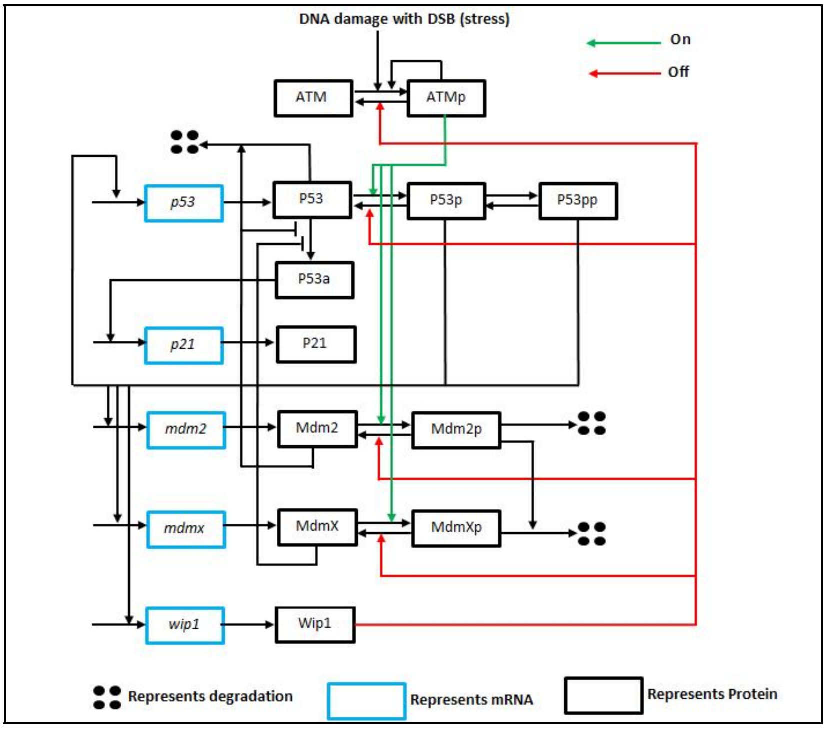

Figure 1. A schematic diagram of the proposed model.

Keywords: *P53 basal dynamics, DNA damage response, Mathematical models, Mdm2, Spontaneous pulses*

Hydrologic Model Parameter Optimisation

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Abstract: Deterministic rainfall-runoff models require parameter calibration with the aim of matching the modeled streamflow record to an observed record as closely as possible. Much attention has been focused on automated methods of model calibration using meta-heuristics, such as genetic algorithms. In this study, two meta-heuristic algorithms were compared: the shuffled complex evolution (SCE) algorithm and a real coded genetic algorithm (GA). The GA was modified with a fitness scaler based on a Boltzmann distribution, which was used to adjust the level of elitism of the selection operator. This was found to improve the performance of the GA. The algorithms were compared using a range of configurations on two test problems - the two parameter Rosenbrock function and the six parameter Hartman function. A relatively small number of objective function evaluations were allowed so as to test the ability of the functions to converge under adverse conditions (that is, limited computational runtime). These functions were found to be best solved with different strategies. The Hartman function was found to respond better to a more elitist strategy, and the Rosenbrock function was solved with a more egalitarian strategy with higher population diversity. On both functions, the best configuration of the SCE algorithm was found to perform favorably compared to the best configurations of the GA.

The best performing configurations of these algorithms were applied to the calibration of a rainfall runoff model of a catchment in Tasmania. The model was a two-tap Australian Water Balance Model (AWBM) consisting of eight parameters, with 10 years of data and a six month warm up period. 20 trials were performed on each algorithm, and in each trial the data were randomly split into train and test sets of nine and one year's data respectively. The more egalitarian strategies (which maintain higher population diversity, as taken from the algorithm configurations found to best suit the Rosenbrock function) were found to be favorable for both the SCE and the GA. When comparing results on the test data, this difference was marginal. The difference in performance was more apparent on the results of the SCE algorithm.

A recommendation of this paper is to develop a catalogue of the performance of several algorithms under different configurations on a range of test objective functions. This could be used to assist in the configuration of meta-heuristics on a range of applied problems, such as the calibration of additional rainfall runoff models.

Keywords: *Hydrology, modeling, calibration, optimisation*

A Hybrid Neural Network Based Australian Wildfire Prediction: a Novel Approach using Environmental Data and Satellite Imagery

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Abstract: Every year catastrophic wildfires during summer months have a major negative socio-economic impact on Australian life and fabric of the society. Early prediction of wildfire prone locations is yet a poorly understood environmental challenge. In this paper, multiple neural networks based hybrid approach has been proposed to predict most probable wildfire locations on a monthly scale. Hybrid architecture constructed with five different neural networks, namely, Feed Forward Back Propagation, Multi-Layer Perceptron, Radial Basis Function, Elman, and Probabilistic networks were trained and tested using segmented image data. Main aspect of this study was to establish a methodology to predict wild fire prone locations as spots on the Australian map based on publicly available gridded maps of Australian weather variables and hydrological variables. Images were created from the gridded maps available from Australian Water Availability Project (AWAP) and Bureau of Meteorology (BOM). On the other hand, NASA-MODIS historical active fire image archives for Australia were used as ground truth. . AWAP and BOM provided important and practical hydrological and environmental attributes whereas NASA-MODIS provided ground truth as training targets. The monthly average data of total evaporation, sensible heat flux, precipitation, incoming solar irradiance, maximum temperature and soil moisture from AWAP were used in the study. On top of these, BOM data consists of monthly average wind speed, vapour pressure and relative humidity. Three year period 2008-2010 were studied where all the monthly images were gathered to develop the complete data set, including 9 input images and 1 target image for every month of the three consecutive years. 70% of the data (2008-2009) were used to train all the neural networks where as the monthly image data from 2010 (30% of the data set) were used to test the networks. Independent training and testing were critical for this study to prove the generalization capability of the hybrid architecture based on the neural networks. 94% overall prediction accuracy was achieved from this approach, with 93% sensitivity and 95.3% specificity. Maximum false positive rate was 0.7% whereas overall precision was 96%. The results were very encouraging in predicting probable Australian wildfire locations and represent visually with high overall accuracy.

Keywords: *Wildfire Map Prediction, Neural Network, AWAP, BOM, NASA-MODIS.*

Application of Ensemble Supervised Machine Learning to Calibrate Cosmos Bulk Soil Moisture Sensor

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Abstract: The Australian Cosmic Ray Sensor Soil Moisture Monitoring Network (CosmOz) is a near-real time soil moisture monitoring sensor network distributed in eleven sites across Australia. Cosmos bulk soil moisture sensors are a new technology from Hydroinnova that measure fast neutron counts that are inversely correlated with soil water content, each sensor covers an area of approximately 40 ha. In this paper, an application of Ensemble Supervised Machine Learning (ESML) combined with data from commercial-off-the-shelf capacitance soil moisture probes and meteorological data was used to dynamically calibrate a Cosmos sensor deployed near Fingal in north-eastern Tasmania, Australia. Using 25 capacitance probes distributed in a 200 meters radius around the Cosmos sensor. The capacitance probes were calibrated to provide a realistic estimation of soil moisture that was compared with measurements by the Cosmos sensor. The capacitance probes measured soil water content continuously at half hour intervals at five soil depths down to 50 cm below the soil surface. Data collected over the period 14/02/2013 -20/04/2013from the capacitance probes, were used to train the Cosmos sensor soil moisture predictions using a newly developed ESML approximator based on multiple Adaptive Neuro-Fuzzy Inference Systems (m-ANFIS, where m =25). ANFIS is a type of neural network based on the Takagi–Sugeno fuzzy inference system. Since it integrates both neural networks and fuzzy logic principles, it has the potential to capture the benefits of both in a single framework. The name ANFIS refers to one specific realization of such a system (architecture for a self-adaptive fuzzy system) that takes a fuzzy inference system and tunes it with the back-propagation algorithm based on a collection of input-output data. Prediction performance of this m-ANFIS ensemble was evaluated using training (50%) and testing (50%) paradigms. Soil water content during the measurement period ranged from 3 to 27% at 10 cm depth and 18 to 39% at 50 cm, which low rainfall during this period and in preceding months (summer-autumn). Overall training performance accuracy was around 94% (range 91%-99% for 25 probes) with, and average prediction accuracy for the testing period was 98%. We conclude that m-ANFIS will be useful for calibrating or testing Cosmic ray probes, but further evaluation is warranted during winter and spring, and the importance of errors might vary depending purpose, e.g. general index of landscape wetness versus precise prediction of soil water for driving predictions of crop performance.

Keywords: *CosmOz, Cosmos Sensor, Capacitance Probe, ESML, m-ANFIS*

Development of Intelligent Environmental Knowledge Discovery System (i-EKbase) for Sustainable Precision Agriculture

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Abstract: The ultimate challenge in agricultural decision support systems is to overcome the data unavailability and uncertainty to make the natural resource management efficient to achieve better business objectives. Uncertainty factors in the agricultural and environmental monitoring processes are more evident than before due to current technological transparency achieved by most recent advanced communication technologies. Poor data quality and uncertainties make the agricultural decision support system unreliable and inefficient. This inefficiency leads to failure of agricultural and environmental resource management. It is evident that there is a serious need to capture and integrate environmental and agricultural knowledge from various heterogeneous data sources including sensor networks, individual sensory system, large scale simulated models, patched historical weather data, satellite imagery, domain knowledge and contextual user experience for better decision support with high reliability and confidence. This approach would be able to provide a much wider framework for complementary knowledge validation and meaningful utilization of the acquired knowledge based on autonomous knowledge discovery using machine learning techniques embedded into the integrated data base. Primary project objectives i.e. web based dynamic heterogeneous knowledge integration and knowledge sharing using Linked Open Data (LOD) cloud principles could provide the future pathway to sustainable agriculture. Initially heterogeneous data sources, namely, Bureau of Meteorology-Long Paddock SILO, Australian Water Availability Project (AWAP), Australian Soil Resource Information System (ASRIS), Australian Cosmic Ray Soil Moisture Sensor Network (CosmOz), NASA's LandSAT satellite imagery of continental earth surfaces databases, and Australian Digital Elevation (DED) databases have been considered to develop the proposed historical knowledge recommendation framework called "i-EKbase". This system has been used to complement the real time sensor and sensor network data stream for better decision support. This research study also aims to expand the agricultural sustainability to precision agriculture using high resolution Linked Open Robotics Data (LORD). Agricultural mobile sensing robotics platform would be deployed as high resolution distributed data capturing and processing service made available to the decision support system. Robotics platform guided by the LOD ontology might be able to discover data from "i-EKbase" system and combine it with its own sensor data for precision agricultural decision support. This research aspect is also aiming for "behavioural cloning" research for capturing the manual data gathering and agricultural decision making processes to be incorporated into the automated LORD capturing process. Ultimately this project aims to provide sustainable solutions to the sensing Tasmania (Sense.t) practical projects based on analytics and robotics research. These objectives would be achieved by providing reliable advices on crop management including irrigation scheduling for the farmers and early detection and alerting about crop diseases.

Keywords: *Machine Learning, Semantic Matching, Knowledge Integration, i-EKbase, Linked Open Data cloud, Linked Open Robotics Data, Precision Agriculture.*

Development of a practically-significant ANN-based air pollution forecasting tool with the aid of explicit knowledge through sensitivity analysis

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Abstract: Artificial neural network (ANN) is known as an effective air pollution modelling tool. However, in air pollution modeling studies, ANN tends to be used as a 'black-box' approach, providing reliable concentration predictions but little insight into dispersion mechanisms. In the way they are used, they also fail to identify which meteorological variables are the most important for a particular application or the key time scales needed to adequately capture the variability in emissions. In this study, we propose a methodology for extracting the key information required from routinely-available meteorological parameters and emission pattern of sources present throughout the year (e.g. traffic emissions) to build a reliable and physically-based ANN air pollution forecasting model.

The methodology is tested on NO_2 concentrations for a site near a major highway in Auckland, New Zealand. The basic model consists of a genetically-optimized multilayer perceptron ANN network with one hidden layer for predicting NO_2 concentration using eight predictor variables: wind speed, wind direction, solar radiation, temperature, relative humidity as well as 'hour of the day', 'day of the week' and 'month of the year' (in respective discrete numbers) representing the time variation in emissions according to their corresponding time scales. The nature of the internal nonlinear function of the trained neural network model is then extracted based on the response of the model to perturbations to individual predictor variables through sensitivity analyses. Other variable selection techniques such as forward selection, backward elimination and genetic optimization were also experimented. A simplified model, based on the successive removal of the least significant meteorological predictor variables is then developed, until the subsequent removal results in a significant decrease in model performance. This simplified model is then used to predict air pollution levels for independent data (the subsequent year) at the same site.

With the inclusion of all of the predictor variables and inputs, the model is able to reliably predict air pollution concentrations for the site of interest, explaining 80% of the variance in concentration in the subsequent year. Genetic optimization suggested that all input parameters considered are required for the best performance of the model. However, the simplified model, based on the successive removal of the least significant meteorological predictor variables leaving only surface wind speed and direction as the only meteorological predictors while retaining the hour of the day, day of the week and month of the year inputs resulted in a model that explained 77% of the variability in NO_2 concentrations, based on independent data (data from the subsequent year). Removing the least significant predictors (relative humidity, temperature and solar radiation) did not significantly affect model performance.

The proposed approach illustrates how ANN can be used to identify the key meteorological variables required to adequately capture the temporal variability in air pollution concentrations for a specific scenario: air pollution levels alongside a busy motorway. A similar methodology could be applied to other scenarios in which the meteorology and emission pattern influence pollution concentrations, albeit in different ways, such as for different road emission scenarios or for industrial sources. Analysis of relationships between measured wind speed, direction and concentration revealed that there are noticeable wind speed, wind direction and concentration clusters, and inclusion of an input clustering technique to the present simplified model could further improve model predictions. The proposed technique makes optimum use of expensive routine ambient records and provides a cost effective and reliable alternative approach to air pollution modelling.

Keywords: *Air pollution modelling, artificial neural networks (ANN), sensitivity analysis, meteorology, NO_2 concentrations, motorway*

Diagnostic models for mastitis detection using sensor data from automatic milking systems – current trends and future perspectives

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Abstract: Treatment of any disease has a greater chance of success if detected early. In fact, early detection of diseases not only has clinical benefits for the patient but also economic benefits for the healthcare provider. Artificial neural networks (ANN) are often used as powerful discriminating classifiers for tasks in medical diagnosis including early detection of diseases and ANN offer researchers powerful methods to analyse, model and make sense of complex clinical data across a broad range of medical applications.

Dairy farming is an important component of agriculture worldwide due to the value of milk to human nutrition. Mastitis is one of the most important, costliest and on-going issues in dairy industry and it is specified as an inflammation of mammary gland in response to chemical, bacterial, thermal or mechanical injury. It is associated with economic losses due to decreased milk production and increased veterinary and labour costs. Preventing mastitis and improving milk quality has a crucial impact on improving animal well-being and farm profitability. The final outcomes of these measures strongly ensure that food is produced in a thoroughly hygienic and sustainable manner. Over the past years, great progress has been made in detection of mastitis in early stages and in management and control of mastitis, but this does not mean that these methods and models detect all mastitis cases and control the disease completely. Nowadays, more and more dairy farmers rely on sensors, each of which measure parameters related to milk or cow. Detection of mastitis can be improved by using better indicators or features and/or by improving the models and methods applied to the data. ANN and statistical methods have been used in mastitis detection and there is conclusive evidence that ANN outperform statistical methods in terms of diagnostic accuracy. However, there is still much to do, in particular, in diagnosing accurately the onset of mastitis; these gaps are: (i) Sensitivity of the detection methods used in automatic milking machines needs to be improved. (ii) The current mastitis detection systems must be improved not only to be applied in automatic milking machines, but also in traditional milking systems. (iii) The current and future systems must perform well on a range of breeds and herds and be applied globally to solve this persistent problem faced by all dairy farmers in the world.

In this paper, we present a summary of an extensive survey on reported works in the area of models for mastitis detection based on sensor data from automatic milking systems and discuss the basis of these models. We present current trends and future perspectives on the potential of ANN models to accurately map the progression of mastitis in cows from healthy to mild, subclinical and clinical stages and then specify where the health of a cow lies in this full mastitis spectrum. This paper aims to evaluate and compare previous model results and focus on future challenges and approaches to meet them successfully.

Keywords: *Artificial Neural Networks (ANN), Early Detection, Mastitis, Sensor Data, Automatic Milking System (AMS)*

Improving PMI based input selection by using different kernel bandwidths for artificial neural network models

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Abstract: Despite the widespread application of artificial neural networks (ANNs) in hydrology, there is still a lack of a systematic approach for their development. In particular, input selection, which is still predominately based upon a trial and error approach, is the first step during the development of ANNs and determines the quantity and quality of information used in ANN modelling. One input selection method that shows promise and has been used extensively in water resource engineering is partial mutual information (PMI). PMI based input selection consists of probability density function (PDF) based mutual information (MI) estimation and kernel regression based residual estimation, both of which require kernel bandwidth estimation. Although use of PMI can effectively determine the relevance and redundancy of candidate inputs and is applicable to non-linear problems, as the Gaussian Reference Rule (GRR) is the most commonly used bandwidth estimator, it generally relies on the assumption that the modelling data follow a Gaussian distribution during kernel based PDF estimation. However, the impact of the type of distribution on PMI performance has not been assessed. This is particularly important in water resources applications, as the distribution of data can be highly non-normal. In this paper, the impact of the sensitivity of different data distributions and the effectiveness of eight different bandwidth estimators (i.e. GRR, biased cross validation (BCV), 2-stage direct plug-in (DPI), a combination of BCV and DPI, smoothed cross validation (SCV), single variable optimization (SVO), and GRR and DPI with diagonal bandwidth matrix) on the accuracy of PMI based input selection is assessed for a number of synthetic and semi-real case studies. Seven typical distributions (i.e. normal, log-normal, exponential, gamma, Person Type III, log-Pearson type III, and extreme value type I) in hydrology are adopted in all benchmark models. The three analysed benchmark models include one linear exogenous auto-regressive (EAR) time-series model, one threshold exogenous auto-regressive (TEAR) time-series model, and one non-linear model (NL). The semi-real case studies are river salinity prediction at Murray Bridge and flow forecasting in the Kentucky River basin, which cover both water quality and quantity problems. Results of all benchmark models indicate that the accuracy of the PMI based input selection is clearly influenced by the distribution of the data. The input selection accuracy of the PMI based method is found to be proportional to the degree of normality of input and output data when the GRR is used. Significant improvements of PMI based input selections are found with bandwidth estimators that have less dependence on the Gaussian assumption. If the majority of inputs and output data follow Gaussian or nearly Gaussian distributions, the GRR based bandwidth estimator should be used (with selection accuracy over 90%) in both of the MI and residual estimation by considering the trade-off between selection accuracy and efficiency; if most of the inputs and output follow slight to moderate Gaussian distributions ($\text{skewness} < 5.0 \;\&\; kurtosis < 30.0$), the recommended bandwidth estimator is the DPI (with selection accuracy improved by 20%-30%) for PDF estimation and the GRR for residual estimation respectively; if extremely non-Gaussian distributions ($\text{skewness} \geq 5.0 \;\&\; kurtosis \geq 30.0$) pre-dominate inputs and output data, PDF estimation and residual estimation should adopt the GRR/DPI and the SVO, respectively (with selection accuracy improved by 10%-20%), to achieve an appropriate balance between selection accuracy and efficiency. The established guidelines of appropriate kernel bandwidth estimators cover broad problem scenarios and have the potential to assist with developing more robust and reliable ANNs in environmental modelling.

Keywords: *Artificial neural networks, partial mutual information, bandwidth estimators, degree of normality*

Fuzzy Representation and Aggregation of Fuzzy Cognitive Maps

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Abstract: Typically, complex systems such as socio-ecological systems are ambiguous and ill-defined due to human-environment interactions. These systems could be participatory systems which involve many participants with different levels of knowledge and experience. The various perceptions of the participants may need to be combined to get a comprehensive understanding and useful knowledge of the system. Modelling these systems involves a high level of uncertainty and soft computing approaches based on the concept of fuzzy logic offer a way to deal with such uncertainty. Fuzzy cognitive map (FCM) incorporates fuzzy logic and has proven its efficiency in modelling and extracting knowledge from various qualitative complex systems. However, the literature shows a lack of appropriate ways to incorporate imprecise human perception in fuzzy form in FCM representation and to deal with these fuzzy values in aggregation of multiple FCMs into a group FCM. The aim of this paper is to provide adequate methods for both representation and aggregation of fuzzy values in FCMs. For FCM representaion, this paper utilizes a 2-tuple fuzzy linguistic representation model Herrera and Martinez (2000a) to represent the FCM connection values in a fuzzy way. This model can represent and deal with linguistic and numeric fuzzy values without any loss of information, and it keeps the consistency of these values throughout any subsequent computational processes.

For FCM aggregation, which is the first step, this paper proposes a fuzzy method to combine linguistic and numeric fuzzy values at the same time. In the second step, it proposes a new calculation method to assess the different levels of knowledge of FCM designers (FCMs' credibility weights). These credibility weights of FCMs are then used in the proposed fuzzy aggregation method for a better representation of contrasts between participants resulting from their varied experiences and preferences. For the first step, the 2-tuple fuzzy model is used to represent the FCM connection values during the aggregation process, and therefore the connection values of the group FCM resulting from the aggregation process will be fuzzy values. For the second step, this paper utilizes the Consensus Centrality Measure (CCM) proposed in Obiedat et al. (2011) to calculate a credibility weight for each FCM.

Keywords: *Fuzzy cognitive map, 2-tuple fuzzy linguistic representation model, consensus centrality measure, credibility weight, FCM fuzzy representation, FCM fuzzy aggregation*

Using genetic programming for symbolic regression to detect climate change signatures

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Abstract: Most often, climate change signals are slow moving (in human terms), low amplitude changes embedded in high amplitude, noisy data. There are many techniques for extracting such signals. This paper introduces a technique which in contrast with empirical methods produces a decomposition of a time series into a set of equations plus a “residual”. This is referred to as stepwise symbolic secomposition (SSD). The extraction of symbolic equations in lieu of empirical functions assists with characterization of time series.

This paper takes two examples of climate data, and applies two different techniques for characterising the low amplitude, slow change embedded therein. The record of CO_2 levels at Mauna-Loa since March 1958, is used to demonstrate and contrast empirical mode decomposition (EMD), and SSD.

The mean monthly tidal gauge records from the small number of gauges which have more than 120 years of data are analysed in more detail by SSD, then three techniques are used to characterize the residual. The techniques are (a) LOESS smoothing, (b) EMD, and (c) high order polynomial regression.

SSD uses a genetic programming system called Eureqa from Cornell Creative Machines Lab guided by an information metric, to extract the most compact informative function it can at each step; the process is repeated on the residuals until no sufficiently informative function is found. EMD and SSD are in stark contrast in the order in which signals are decomposed. EMD extracts high frequency components first. SSD extracts components based on a mixture of parsimonious representation and variance explained. EMD leaves a low frequency filtrate of the signal in its residue, SSD tends to operate as a broad band filter, leaving high frequency noise plus a possible low frequency signal. EMD, LOESS and polynomial fitting all serve to extract low frequency components of the signal from this SSD residual.

For the set of tidal gauge data, in the absence of a change in global sea level rise, the SSD procedure should randomize all segments of residual signals equally – the residual should be whitened with respect to the initial signal. It is shown however that late 20th century portions of the residuals show behaviour that is consistent with accelerating sea level rise in keeping with the bulk of the literature.

Keywords: *Genetic programming, empirical mode decomposition (EMD), stepwise symbolic decomposition (SSD), sea level rise.*

Modeling rapid stomatal closure with Synchronous Boolean Network Approach

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Abstract: The phytohormone Abscisic acid (ABA) is an endogenous messenger in plant abiotic stress responses. Drought stress increases the level of ABA triggering the fastest adaptive physiological response of plants- closure of stomata (guard cells). Understanding gene/protein expression involved in stomatal closure has great importance to genetic modification of plants to survive in severe climatic conditions. However, systems level information that defines the communication pattern of the related network of cellular molecules is not yet known. This study integrates fragmentary information collected from literature to define the dynamics of ABA signaling in rapid closure of stomata through a synchronous Boolean model. Stomatal closure in broad terms is a combined result of organic and inorganic ion regulation to release water from the guard cells through osmosis, and rearrangement of Actin to facilitate resulting stomatal movement.

Our network consists of 57 nodes and their interaction dynamics defined in accordance with past experimental results to regulate stomatal closure. Perturbation analysis was conducted to identify the essential elements crucial for the above mentioned global functions of pumping out water and stomatal movement. It revealed that destruction of ABA receptor complex (PYR/PYL, PP2C and SnRK2 proteins) made stomata insensitive to closure as a result of disruption of signal transmission to downstream regulators.

It was identified that plasma membrane outward ion channels GORK and SLAC1 are crucial for pumping out water by reducing the osmotic load inside the guard cell which facilitates osmosis. Inhibition of MAPK kinases and cytosolic alkalization, as being important regulators of SLAC1, and membrane depolarization, important for GORK, showed drastic effect on the stomatal closure. In contrast, overexpression of plasma membrane H^+-pumping and potassium-in channels inhibit stomatal closure by enhancing the osmotic concentration and there by attracting water inside.

Loss of function of Actin rearrangement resulted in a loss of stomatal closure as structural rearrangement of guard cell are necessary to facilitate the cell shrinkage. Disruption of Reactive Oxygen Species or their regulators (RBOH, PA, PLD or RCN1), SCAB1 protein and overexpression of AtRAC1 showed drastic effects on structural rearrangements.

Perturbation analysis revealed that the number of elements crucial to stomatal closure comprises about 30% of the network; and thus stomatal closure is robust against perturbation in the other 70% of network elements. These results are in agreement with experimental findings and indicate potential redundancy with respect to stomatal closure.

Keywords: *ABA signaling, Stomatal closure, Boolean Network, limit cycles, attractors, oscillations*

Comparison of computational and semi-empirical aerodynamics tools for making fit-for-purpose modelling decisions

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The weapons modelling and simulation community relies on a suite of aerodynamic data generation tools that span the empirical to numerical solution methods. These tools compute aerodynamic coefficients at differing fidelities and computational costs, where the tools that require the least amount of computational cost are also usually the least accurate. The intended result of this study was to define a set of best practices for frequently used aerodynamics packages. Missile DATCOM, NASA Cart3D and Metacomp CFD++ were chosen as a representative subset of the existing aerodynamics tools. This study investigated two distinct missile systems spanning the subsonic, transonic and supersonic flight regimes. Generated lift, drag and pitching moment coefficients from the three software packages were compared against wind tunnel data.

It was found that CFD++ produced the lowest errors of all the tools tested, highlighting the applicability of the tool to all tested flow regimes, and is recommended for use where the highest fidelity solution is desired and the result is not highly time critical. The results for Cart3D showed that it may be used to obtain a solution for supersonic cases where a small margin for error in the results is acceptable. However, the accuracy was lower for other flow regimes, especially the transonic regime where Cart3D produced erroneous results. Missile Datcom produced erroneous results for the non-conventional geometry tested, however it was able to produce medium fidelity results for conventional air to air missile shapes. The ability of Missile Datcom to produce results very quickly highlights its utility for quick-look analysis of conventional air to air systems.

The quantified errors and solution times are presented in a format that will aid modellers in making appropriate fit-for-purpose decisions for aerodynamic data generation as well as in assisting managers in deciding project milestones and delivery dates.

Keywords: *CFD++, Missile Datcom, Cart3D, validation, wind tunnel, comparison*

On Wavelet based Modeling of Neural Networks using Graph-theoretic Approach

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Abstract: A graph is an abstract representation of complex networks. Many practical problems can be represented by graphs. With graphs, it is possible to model many types of relations and process dynamics in physical, biological, social and information systems.. More specifically, the relationships among data in several areas of science and engineering, e.g. computer vision, molecular chemistry, molecular biology, pattern recognition, and data mining, can be represented in terms of graphs. For example, graph analysis has been used in the study of models of neural networks, anatomical connectivity, and functional connectivity based upon functional magnetic resonance imaging (fMRI), electroencephalography (EEG) and magnetoencephalography (MEG).

Of late, many important properties of complex networks have been delineated and a significant progress has been made in understanding the relationship between the structural properties of networks and the nature of dynamics taking place on these networks with the help of graph theoretical approach. These developments in the theory of complex networks have inspired new applications in the upcoming field of neuroscience.

In this work, a novel wavelet based neural network stochastic model that extends existing neural network methods for processing the data represented in a graph domain is proposed. Here, the approach is based on defining random walks on arbitrary infinite graphs representing neural networks. The random walk itself is a stochastic process characterized by some probability distribution. More so, random walks exhibit fractal-like patterns that, in turn, legitimately allow the use of wavelet methods for visualizing and processing. The wavelet transform is constructed for the random walk represented by Gaussian function with the vanishing momenta engendered by Gaussian function as an analyzing function. The wavelet transform so devised is well defined since both the testing function and analyzing function employed in the construction belonged to a class of Gaussian functions. Theory is further extended to discrete format for numerical implementation of the transform. The robustness of the proposed model as against the existing ones has been justified by highlighting the potential applications of neuroscience.

In this work, an attempt is made to combine wavelet transform and graph theory. The work is not example specific but it provides a theoretical framework for analyzing the complex structures of neural networks representing various neuroscientific phenomena.

Keywords: *wavelet transform, graph neural networks, random process, neuroscience*

A new heuristic method for generating the initial population of evolutionary algorithms for the optimisation of water distribution systems

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Abstract: Genetic algorithms (GAs) have been used extensively for the optimisation of water distribution systems (WDSs). Although they have been demonstrated to be efficient and effective in finding near-optimal solutions for relative simple benchmark problems, computational challenges have become a significant barrier to the wider uptake of GAs for the optimisation of large, real-world WDSs. This is because the computational effort required by hydraulic simulation generally increases dramatically with increases in network size and complexity. A number of different strategies have been employed to improve the computational efficiency of GAs in previous research and there has been increased recognition of the importance of being able to find near-optimal solutions within the computational budgets that are typically available in practice. It has been shown that the initial population is an important factor affecting the efficiency and effectiveness of GAs. In previous studies, intelligent methods have been used to determine the initial population of GAs which were able to find good solutions for larger WDSs with reduced computational effort. However, limited research considered the use of domain knowledge about WDSs in the development of intelligent initialisation methods. In this study, a new method of incorporating domain knowledge into the generation of the initial population of GAs for the least-cost design of WDSs is introduced and its performance compared with that of a number of alternative initialisation method for a number of WDSs of varying complexity.

In the proposed method, domain knowledge is taken into account in the following two steps for generating the initial population, including:

- Assigning pipe diameters that are inversely proportional to the distance to the source, which considers knowledge that upstream pipe diameters are generally larger than those further downstream;
- Adjusting assigned pipe diameters so that flow velocities are less than a pre-defined threshold value, which is based on engineering knowledge that the velocities in most pipes are within a certain range for the optimal solution;

In addition, a distribution function is used in generating the initial population from the adjusted pipe diameters to maintain the solution diversity. The proposed domain knowledge-based (heuristic) method for generating the initial GA population is applied to seven case studies of increasing size and network complexity. In addition, its performance is compared with that of another heuristic method (Kang and Lansey 2012) and two non-heuristic initialisation methods (i.e. random and Latin hypercube sampling).

The results obtained show that both heuristic methods provided significantly better starting points for GAs than those obtained using the non-heuristic initialisation methods. It is also found that GAs using heuristic initialisation methods significantly outperformed GAs using non-heuristic initialisation methods during the early stages of the optimisation process, although all methods ultimately provided similar near-optimal solutions when a sufficiently large computational budget was provided. Overall, the GAs using heuristic initialisation methods consistently found similar, if not better, near-optimal solutions than GAs using non-heuristic initialisation approaches. This was achieved with dramatically improved efficiency, with the advantage being more prominent for larger and more complex WDSs. In addition, the heuristic initialisation method introduced in this paper generally outperforms the Method of Kang and Lansey (2012).

Keywords: *Genetic algorithms (GAs), Water distribution systems (WDSs), optimisation, domain knowledge, heuristics, initialisation methods*

Building adaptable agent-based models – application to the electricity distribution network

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Abstract: Agent-based modelling (ABM), like other modelling techniques, is used to answer specific questions from real world systems that could otherwise be expensive or impractical. Its recent gain in popularity can be attributed to some degree to its capacity to use information at a fine level of detail of the system, both geographically and temporally, and generate information at a higher level, where emerging patterns can be observed. This technique is data-intensive, as explicit data at a fine level of detail is used and it is computer-intensive as many interactions between agents, which can learn and have a goal, are required. With the growing availability of data and the increase in computer power, these concerns are however fading. Nonetheless, being able to update or extend the model as more information becomes available can become problematic, because of the tight coupling of the agents and their dependence on the data, especially when modelling very large systems.

One large system to which ABM is currently applied is the electricity distribution where thousands of agents representing the network and the consumers' behaviours are interacting with one another. A framework that aims at answering a range of questions regarding the potential evolution of the grid has been developed and is presented here. It uses agent-based modelling to represent the engineering infrastructure of the distribution network and has been built with flexibility and extensibility in mind. What distinguishes the method presented here from the usual ABMs is that this ABM has been developed in a compositional manner. This encompasses not only the software tool, which core is named MODAM (MODular Agent-based Model) but the model itself. Using such approach enables the model to be extended as more information becomes available or modified as the electricity system evolves, leading to an adaptable model.

Two well-known modularity principles in the software engineering domain are information hiding and separation of concerns. These principles were used to develop the agent-based model on top of OSGi and Eclipse plugins which have good support for modularity. Information regarding the model entities was separated into a) assets which describe the entities' physical characteristics, and b) agents which describe their behaviour according to their goal and previous learning experiences. This approach diverges from the traditional approach where both aspects are often conflated. It has many advantages in terms of reusability of one or the other aspect for different purposes as well as composability when building simulations. For example, the way an asset is used on a network can greatly vary while its physical characteristics are the same – this is the case for two identical battery systems which usage will vary depending on the purpose of their installation. While any battery can be described by its physical properties (e.g. capacity, lifetime, and depth of discharge), its behaviour will vary depending on who is using it and what their aim is. The model is populated using data describing both aspects (physical characteristics and behaviour) and can be updated as required depending on what simulation is to be run. For example, data can be used to describe the environment to which the agents respond to – e.g. weather for solar panels, or to describe the assets and their relation to one another – e.g. the network assets. Finally, when running a simulation, MODAM calls on its module manager that coordinates the different plugins, automates the creation of the assets and agents using factories, and schedules their execution which can be done sequentially or in parallel for faster execution.

Building agent-based models in this way has proven fast when adding new complex behaviours, as well as new types of assets. Simulations have been run to understand the potential impact of changes on the network in terms of assets (e.g. installation of decentralised generators) or behaviours (e.g. response to different management aims). While this platform has been developed within the context of a project focussing on the electricity domain, the core of the software, MODAM, can be extended to other domains such as transport which is part of future work with the addition of electric vehicles.

Keywords: *Agent-Based Models, modularity, composability, electricity distribution networks*

Numerical simulation of a high viscosity bubble column

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Abstract: The objective of this work is to develop fluid dynamic model to simulate a high viscosity bubble column for CO_2 absorption in Ionic Liquids (ILs). A very promising solvent for CO_2 capture and conversion are ionic liquids (ILs); ILs consist of a wide group of salts, which are liquids at room temperature, have low vapor pressure, high ionic conductivity and thermal stability. However, the use of ILs for industrial CO_2 depletion has a series of technical and economic issues that must be solved if this strategy is to be implemented. A very important drawback of ILs used for gas removal is its high viscosity, reaching values above 0.010 Pa·s which results in a decrease of the overall mass transfer rate and an increase in the power required for pumping and mixing. In order to elucidate the hydrodynamic behavior in a bubble column for CO_2 absorption with one gas feed inlet, a Computational Fluid Dynamic (CFD) model was developed, which was experimentally validated through a laboratory scale bubble column. To simplify the calculations and increase the accuracy of the results, the system was modeled as a single rising bubble which permits the estimation of the bubble rising velocity and the change of the bubble shape and size during its displacement. The model approach consists in a simplified two-dimensional multiphase flow model which considers the liquid solvent as a Newtonian fluid. The laminar, isothermal, and non-stationary hypotheses for both phases is applied. To model the displacement of the gas-liquid interface, the Level Set method was used. The laboratory tests were carried out using water-glycerol mixtures (58 %, 78 %, 84 % and 88 % by weight) and two Imidazolium type ionic liquids (pure [bmim]BF_4 and [bmim]PF_6). To compare the results obtained from the laboratory and the simulations, the drag coefficient for gas bubbles in liquids was used which correlates the fluid physical properties of fluids and the bubble equivalent diameter and terminal velocity. The results were also compared with predicted values obtained through a new correlation for the drag coefficient of single rising bubbles in ILs proposed by Dong et al. (2010). The results indicated that the CFD model is in good agreement with the experimental results, particularly for bubble Reynolds numbers below 5. Above this value, the model tends to underestimate the bubble terminal velocity which can be explained by the effect of the high velocity gradients close to the gas-liquid interface. Future steps will involve improving of the computational mesh, a parametric analysis of the reintialization parameter and the parameter controlling the thickness at the interface transition zone. Acknowledgments. This work was supported by FONDECYT post-doc N°3120138 from CONICYT (Chile).

Keywords: *Computational Fluid Dynamic, Bubble Column, Ionic Liquid.*

Modelling unglazed solar collectors for domestic water heating in Valparaíso (Chile)

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Abstract: The objective of this work is to develop a computer routine capable of estimating the solar energy potential of an urban area of Valparaiso (Chile) composed of 366 households, using unglazed Domestic Hot Water Solar Systems (DHWS) integrated into the roofs. It was studied the thermal performance of each solar system considering the spatial arrangement of roofs, building materials as well as local meteorological data. In particular, it discusses the use of galvanized steel roofs as a solar collector which has a high thermal conductivity and is one of the main building materials in Valparaiso. The methodology used for the calculations includes the modeling and simulation of DHWS at the individual house level considering the potential solar energy incident on each tilted roof and the heat transfer in each DHWS according to the Duffie and Beckman (1991) approach. The solar radiation on roofs was modeled according to the classical transposition method which estimates the total solar radiation as the sum of the direct, diffuse and reflected component of incident solar radiation. The calculations were performed over a period of one year using monthly average hourly instantaneous data. The assumptions for the heat transfer model are the following:

1. The heat transfer is in steady state
2. The flow regime inside the tubes is laminar
3. The air movement around the absorber is a consequence only of the wind
4. The temperature gradient through tube wall is negligible
5. The short and large wave radiations are distributed homogeneity through the system
6. There are not gradients of temperature inside the storage tank
7. The heat losses in the lateral and backside part of the collector are negligible.

The results show that during the year, the useful energy gain of the system suffers a strong variability, with values over 3000 W by roof between 12 and 14 PM local time during summer, falling to values lesser than 1000 W by roof between 12 and 16 PM local time during winter. The monthly average temperature at the system outlet can reach values over 40 °C (average inlet temperature of 21 °C) by household between 12 and 14 PM local time during summer, falling to values lesser than 25 °C (average inlet temperature of 16 °C) during the winter season. The thermal efficiency of each household between 12 and 16 PM oscillate between 2 and 12 % during the year. This variability is mainly related to the monthly and daily evolution of heat losses due to natural convection and radiation, as well as roof tilting angle and orientation.
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Keywords: *Solar energy, Unglazed solar collectors, Solar mapping*

Multi-Scale Modeling Of Materials: A Basis for Computational Design

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Abstract: This paper will present a multi-scale of corrosion that spans scales from molecular scale (where it considers the binding of inhibitor to metal surfaces) to the continental scale where it considers ocean production of marine aerosols and the aerosols subsequent transport across continents. The multi-scale model has been developed in order to both guide the development of new corrosion resistant materials and to aid in their design and selection. Multi-scale modelling will facilitate computational assisted design by allowing the effect of a large number of design variables to be assessed computationally before the final reduced selection can be investigated experimentally.

The combination of macro – micron scale allows a definition of the state of the surface (on a 3 hourly basis) with four states being defined: wet from rain, wet from the wetting of hygroscopic salts, drying, and dry. Then for each these states the rate of corrosion and changes in the nature of the metal/oxide/moisture layer system are predicted. On active metals such as zinc and steel, multi-layers of oxide may develop. Adjacent to the metal surface a compact oxide is observed under certain circumstances. This compact oxide layer dramatically reduces the rate of metallic corrosion. Above, or in the absence of the compact layer, bands of porous oxide may develop with variable porosity from the metal or compact layer interface to the moisture layer. To model this porous oxide a model based on porous-electrode theory has been developed. The porous oxide model (POM) is a continium model that accounts for diffusion, chemical and electrochemical process. In a system where the oxide is semi-conducting (such as zinc or iron) the oxide itself may support the oxygen reduction reaction (ORR). The POM considers the relative rate of the ORR at the metal surface and at the porous oxide-solution boundary. It is found that the ORR occurs both at the metal surface and at the pore boundary but with time as oxygen is depleted at the bottom of the pores the ORR occurs predominantly on the oxide surface. The conditions generated within the porous layer will affect the conditions at the porous layer/compact layer interface and thus affect the compact layer stability. The POM model is then combined with a fine scale model of the condition of and processes within compact barrier oxides. The integration of the state model the POM and the model of the compact oxide will provide both a design and materials selection tool for uncoated metals

Modelling of inhibitor/metal surface interaction is being undertaken to assess the effect of molecular structure and functional groups that lead to effective inhibition. This model combines a range of sub-modules, including modules which cover extensive length scales.

Keywords: *Corrosion, Inhibitor, Coating, Oxide, Multi-scale Modeling*

Planning with Lanier Ultra-Short Stable Slatwings of 1920s-1970s Budget Vacu/Para-planes

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Abstract: Early 1930s witnessed curious 1/2 or 1/3rd usual wingspan, 1-2seat cheap economical Lanier planes flying reliably and extremely stable, even an early student version. They had very low landing speed of a runner i.e. short take-off/landing (STOL). All available Patents since 1929 were collected - the year Airship *Graf Zeppelin* globe-circled - plus many Lanier photos and scientific press releases of Lanier aircraft since then. Prof.Edward M.Lanier, *University of Miami*, had used wide short-span "open top" slat wings to create a partial vacuum lift, thus sucking the plane upward. A Study Group I commissioned applied *FastFlo* Software to Modeling the Wing. This paper attempts to finally enthuse Aero Improvement advocates into reinitiating Lanier plane model testing or full-scale R&D, an activity in which the author has been vitally involved since 1970s. Efficient and quiet Laniers have "great safety", "almost fly themselves", "almost hover", "STOL in 20m", "Every Field an Airport" and "Hangering greatly enhanced"; thus no need of vast airports and hence introducing significant transformation to Public Transport Planning. Only the plane's lifting surfaces and propeller are aeronautical, the remainder fine Engineering.

Keywords: *Unconventional Aircraft, Fluid and Aero Dynamics, Flight, Lanier, Flight Control and Aircraft Mechanical Design.*

A new proposed approach for star grain design and optimisation

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Abstract: The domain of this work is the design of solid fuel grain in rocketry. Star grain configuration is considered to be among the extensively used configurations for the last 60 years. It is well known for its simplicity, reliability, and efficiency. The paper aims to extend the knowledge base for design and optimisation of said grain configuration. The unexplored areas of treatment of ballistic constraints, non-neutral trace, freedom from use of generalized design equations, and sensitivity analysis of optimum design point are treated in detail to bridge the gap left by researchers.

The grain design is vital if designed for high volumetric efficiency with minimum possible sliver. Star grain configuration offers reasonable performance with realistic and practical ranges of web fraction and volumetric loading fraction, though, tail-off and sliver are main disadvantages which, however, are controllable by efficient optimisation scheme. The primary purpose of the proposed approach is to expand the design domain by considering entire convex star family under both neutral and non-neutral conditions. The salient features of this research effort are the ballistic objective function (effective total impulse) and parametric modelling of the entire family of convex star grain configuration using solid modelling module. Internal ballistics calculations are then performed by the equilibrium pressure method.

A set of eight design variables are passed on to the "design of experiments" module. This module keeps the computational resources in check by employing Latin Hypercube Sampling technique for efficient generation of initial population. This population of design variables is then passed on to the Swarm intelligence module which generates the candidate solution points. Now, the candidate solution is passed on to the solid modelling module to perform parametric modelling of grain configuration and to simulate the burning process. This iterative procedure is repeated until the maximum value of effective total impulse is achieved while satisfying the constraints. This process is simulated in MATLAB and the solid modelling module is connected to MATLAB via visual basic.

Optimal design point and important ballistic parameters of throat diameter, burn rate, characteristic velocity and propellant density are then tested for sensitivities by using Monte Carlo simulation. A random sample of size 500 is used to generate a population for testing these parameters on their tolerances. These tolerances are the result of experience in grain design process and manufacturing. This simulation provides essential data set which can be useful prior to the production of large number of solid rocket motors. Furthermore, it enlightens the necessity to obtain statistical data during manufacturing processes.

The proposed approach takes the design of star grain configuration to a new level with introduction of parametric modelling and sensitivity analysis, thus, offering practical optimum design points for use in various mission scenarios. The simulations suggest that the design is adequate from engineering perspective and practically possible for use in solid rocket motors. This approach fulfils the long sought requirement on getting free from use of generalized set of equations for commonly used Star grain configurations. Results showed that few design parameters are sensitive to uncertainties. These uncertainties can be investigated in future by robust design method.

Keywords: *Space Propulsion, solid rocket motor, star grain, swarm intelligence, CAD, parametric modelling, monte carlo simulation*

Impact of calibration data variability on rainfall-runoff modelling performance in data-limited basins

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Abstract: There is a question which comes to the users of hydrological models: which segment of observation data should be used for calibration? Especially when model users face the case of applying models in ungauged or data-limited basins. It is important to make best use of these limited data. Calibration data variability is seldom considered in lumped conceptual rainfall-runoff models although it has significant impacts on modeling performance. In order to study the performance of rainfall-runoff models in data-limited basins (actually, data are non-continuous and fragmented in some basins), we choose to use non-continuous calibration periods to have more independent runoff data for calibration of the SIMHYD model. The Particle Swarm Optimization (PSO) optimization method is used to calibrate the rainfall-runoff models. The Nash-Sutcliffe efficiency (NSE) and percentage water balance error (WBE) are used as performance measures. Average, dry and wet calibration periods are used for study on impact of calibration data variability. Fifty five (55) relatively unimpaired basins all over Australia are tested to obtain general conclusions. The results show that, the rainfall-runoff models have more steady performance when calibrated by average or wet subsets than calibrated by dry subsets, and wet subsets are more suitable for model calibration both in all basins. Calibration data have much impact on arid and semi-arid basins and have little impact on humid and semi-humid basins. The models perform better in humid and semi-humid basins than arid basins. Our results may have useful and interesting implications when hydrological model users at the case of ungauged or data-limited basins.

Keywords: *rainfall-runoff modeling, data-limited, calibration data, variability*

Ray tracing based fast refraction method for an object seen through a cylindrical glass

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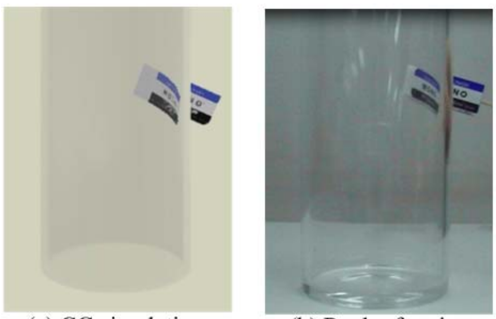
Abstract: In computer graphics, generating realistic images based on physical phenomena is one of the most challenging issues, especially for optical related phenomena such as reflection and refraction. In order to generate such images, there are two major methods: ray tracing and environment mapping. Ray tracing can generate fine images since it traces optical path for each pixel constructing the image, although it takes huge time as the resolution of the image improves and the number and complexity of the objects in the scene increases. On the other hand, environment mapping is based on the images that are previously generated so that it can generate realistic images in real time. Both methods have merits and demerits. Then, many reflection and refraction methods have been developed by utilizing the merits. In general, these techniques are designed to be used for any objects that are constructed with any numbers of polygons. On the other hand, we can calculate image distortion caused by reflection or refraction if the shape of the reflective object or transparent material is geometrically defined. Therefore, this paper proposes a new technique that calculates the positions of vertices constructing display objects, which are deformed by being seen through a transparent material. The refraction calculation is accurate because it is performed with the same method as ray tracing. In addition, the proposed method is faster than ray tracing since the calculation is performed for the vertices that construct the display objects instead of pixels that construct the final image because the number of the pixels is huge compared to that of the vertices.

We can calculate the movement vectors of vertices that construct display objects by using Snell's law if the transparent material is geometrically defined. In the case of parallel glass, refraction occurs twice because ray of light is refracted when it enters and leaves the glass. On the other hand, in the case of cylindrical glass, there are two types of refractions. Refraction occurs four times if ray passes two curved planes, and refraction occurs twice if it passes the verge of the glass. In addition, no refraction occurs if ray does not pass the transparent material. Then, three types of objects that are distorted or not distorted according to the refraction times should be generated, and the pixels constructing the final image should be indexed according to the refraction time. For indexing of the pixel, depth peeling method can be used, which detects for each pixel how many times of peeling are required to remove the transparent material. Finally, the refracted image is generated by combining the three different types of images pixel by pixel.

Figure 1 is one of applications by using the proposed method and it shows the comparison between the real image and CG simulation. The display object is an eraser and the transparent material is a cylindrical glass. Refraction occurs four times in the inside of the glass, while no refraction occurs in the outside of it. In the inside of the glass, the eraser is considerably distorted and the refractive image can be displayed in real time according to the eraser movement. In the simulation, we used a normal PC that has Intel Corei7 3.4GHz CPU, 8GB main memories, NVIDIA GeForce GTX570 GPU, and measured the performance of the method. For the final image with 1,600 × 1,200 resolution, the average of the frame rate by the proposed method was 96 FPS (Frames Per Second) to display refracted objects that are composed of 100,000 vertices, while that by GPU based ray tracing method was 26 FPS.



(a) CG simulation (b) Real refraction

Figure 1. Comparison of the refractive image by CG simulation and that by real phenomenon.

Keywords: *Computer graphics, physical simulation, ray tracing, refraction*

A balancing act in heterogeneous computing – Developing the AWRA-Landscape data assimilation system

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Abstract: The Australian Water Resource Assessment Landscape (AWRA-L) model is a landscape surface water model running at a daily time step on 277,770 grid cells. To make the best use of observations to guide the model results, an Ensemble Kalman filter (EnKF) technique is used to assimilate remotely sensed satellite data. It executes one hundred instances of the model in parallel, leading to substantial computational challenges by hydrologic modelling standards. The AWRA-L data assimilation system was originally implemented in the R language. While it is a concise implementation, runtime performance is not adequate to perform experiments at the scale of Australia, even using computational clusters.

The AWRA-L data assimilation (DA) system must perform in exploratory research as well as in a broader operational model orchestrated by the software product Delft-FEWS (Flood Early Warning System) at the Bureau of Meteorology. The infrastructure available in each case is significantly different, as is the prioritisation of features. Software use in a research context requires execution speed as well as the possibility for the principal researcher to perform new experiments. These can be done on compute clusters, optionally with state of the art devices with Graphical Processing Units (GPU). The operational version of AWRA-L DA is designed to fit in a time stepping FEWS workflow. This workflow is such that AWRA-L DA must be run over the whole nation for a given time step before stepping temporally, a constraint not present in the research context. To reuse existing model code, the C# language is chosen for the core of AWRA-L DA, with a path to test and, if suitable, migrate to OpenCL for some of the computations. The operational system must scale well within a single process with multiple threads to maximize the use of the operational infrastructure. For the research needs it must also scale well across compute nodes, where network throughput is more likely to become a significant performance bottleneck.

In order to assess the performance of computing on GPU devices for the AWRA-L DA, we use OpenCL.NET to run OpenCL code from the C# system. AWRA-L DA is added to an AWRA system where an implementation of the model already exists for calibration purposes. Calibration and DA contexts differ, notably in terms of primacy of the temporal versus spatial dimensions of the problem for computations. A custom implementation of AWRA-L for DA is necessary. We trial a code template technology to manage these parallel implementations, where the use of object-oriented and generic programming is technically not sufficient to limit duplications. The final assessment of the system in terms of runtime shows that the C# implementation scales well in a multi-threaded mode up to six to eight cores, enabling the efficient use of the resources of the operational system. A multi-process version dividing the problem spatially is used for research purposes, complemented with a final collation of partial results. Combining multi-threading and multiple processes in a cluster environment, we can balance between multi-threading overheads and the input/output (I/O) bottlenecks of a large number of processes. A usage with thirty two processes, each with two threads, is chosen for research experiments. We project that the use of a native language such as C++ would have brought an additional raw runtime performance of ~40%. The gain would however be less in a real use case due to I/O throughput considerations. Our trial of OpenCL, even limited to portions of the code already shows an improvement of 50% over a single threaded pure C# version. These figures suggest that were more runtime performance gains necessary for a problem of gridded nature such as AWRA-L DA, there are compelling reasons to consider GPU enabled computations.

Keywords: *High performance computing, NET, OpenCL, R language, data assimilation*

Reversing the design process to aid in complex engineering problems

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Abstract: Design engineers prefer to have multiple performing solutions, rather than a single optimum. This set of design alternatives gives desired flexibility to engineers. The motivation of current research effort stems from the question that “Can the design process be reversed?” Every design endeavor has a specific set of stringent performance requirements to meet. So, if we “reverse” the classical design process and start from those performance requirements, we should obtain a design point meeting such requirements. The traditional inverse engineering methods depends greatly on specific domain knowledge and usually, can effectively facilitate the inversion for a specific application problem. However, it is very difficult to apply them into diverse design scenarios where any of the presumed conditions is violated. Development of a more generic and robust approach is deemed necessary to achieve reliable design results in various design endeavors. This work also aims to answer the question, How to find sufficient design alternatives sufficing a given performance level? In doing so, we also intend to keep check on the computational budget (reduce the total number of function evaluations) even for high dimensional problems.

This work addresses these needs by proposing a methodical approach to identify the feasible region(s), of the large design space of complex problems, containing design points meeting the same or little-less desired performance level. In this way, continuous and/ or discontinuous segments of design space can also be identified. Such regions are anticipated to meet acceptable performance levels. The proposed approach can be cast as a rough set based design methodology. The procedure identifies the design spaces corresponding to the required objective function value, by extracting rules from input-output information system, instead of an approximation of the objective function. The discretized decision system/ table and extracted rules act as transparent metamodel establishing relationship between performance space and design variable space. Thus the proposed method can identify multiple global optima in contrast to a single optimum identified by traditional global optimizers. Latinized Hypercube Sampling is employed to generate information/ decision system to identify attractive spaces even for complex high dimensional problems, thus, limiting total function evaluations to a modest number.

The performance of the proposed procedure has been tested and, thus, validated by the trajectory modelling problem. The inverse design approach based on rough sets is intended for initial conceptual design purposes, thus, providing an immediate insight on the performance prior to the detailed design phase.

Keywords: *Engineering design, reverse design process, optimization, trajectory modelling, air launched satellite launch vehicle.*

A modern take on the theoretical modelling of inertial properties of a human body for biomechanical simulations

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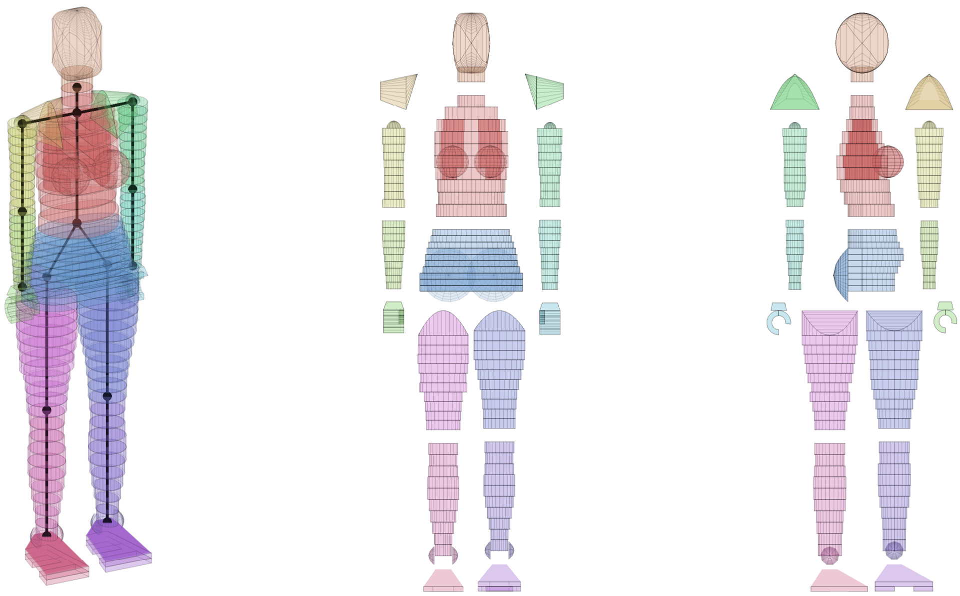
Abstract: The accurate estimation of inertial properties of individual body segments, including mass and moment of inertia, for biomechanical modelling and simulation is important in predicting realistic movement patterns. These properties must be subject-specific, as body shape and weight distribution varies significantly between members of the human population. One method of estimating these parameters is by using anthropometric measurements as inputs into a geometric humanoid model, in which each body segment is comprised of a certain number of regular volumetric shapes depending on the complexity of the shape and on the complexity of the model.

Several of these geometric body segment parameter models have been proposed, among which the work of the late Herbert Hatze (1937–2002) stands out as the most detailed and accurate. Due to the mathematical complexity of his model (1979–1980), his work has not been widely used for biomechanical research; while often cited, it has rarely been reproduced.

In this paper, an open source redevelopment of Hatze's model is described, which includes a visualisation component that allows the 3D geometry to be accurately depicted for the first time. An analysis is performed which relates the accuracy of the model to the number of anthropometric measurements taken and suggests a reduced-order version of the model using interpolation. In order for the model to be more widely used and hopefully improved in time, the Matlab code for this work is made freely available for use by the research community.



Keywords: *Biomechanics, body segment parameter estimation*

Modelling and analysis of the global stability of Blasius boundary-layer flow interacting with a compliant wall

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Abstract: Theoretical and experimental studies have shown that compliant walls are able to reduce the growth rates of unstable Tollmien-Schlichting waves (TSWs) that are the conventional route to boundary-layer transition in low-disturbance environments. Accordingly, transition can be postponed by an appropriately designed compliant coating adhered to an otherwise rigid surface, thereby leading to a potentially significant reduction of skin-friction drag in marine applications. The more compliant the wall, the greater is the suppression of TSWs. However, the compliant wall can also support unstable wall-based waves that typically occur when the wall is too compliant and thereby undermine the overall flow-stabilization strategy. Accordingly, when designing useful complaint coatings, it is necessary to take into account all of the possible instabilities of the fluid-structure interaction (FSI) system.

The majority of previous studies utilize local-stability analyses based upon the assumptions of an infinitely long compliant wall and parallel-flow to identify and characterise the system instabilities while numerical simulation has been used for walls of finite extent. In contrast, we carry out a bi-global linear stability analysis in the present study of the FSI system. We model the flow using a combination of vortex and source boundary-element sheets on a computational grid while the dynamics of a plate-spring, Kramer-type, complaint wall are represented in finite-difference form. The assembled FSI system is then couched as an eigenvalue problem and the eigenvalues of the various flow- and wall-based instabilities are analyzed for a range of system parameters.

The key findings of the study are that coalescence – or resonance - of one of the structural eigenmodes with either the most unstable TSW or a travelling-wave flutter (TWF) mode can occur. This renders the convective nature of these instabilities to become global for a finite compliant wall. A local analysis of the temporally unstable modes shows that besides the TSW and TWF modes, a divergence-type mode associated with the structural behaviour can additionally yield global instability. Finally, a non-modal analysis reveals that the behaviour of flow-based instabilities over a structurally damped compliant wall in response to an initial disturbance shows slightly lower transient growth and energy advection than occurs over a rigid wall in the sub-resonance combination of wall and flow parameters. However, for system conditions that yield resonance-type behaviour, transient growth is significantly larger than that which occurs over a rigid wall.

Keywords: *Fluid-structure interaction, Global stability, Blasius flow, Compliant wall, Non-modal analysis*

A High Performance, Agent-Based Simulation of Old World Screwworm Fly Lifecycle and Dispersal using a Graphics Processing Unit (GPU) Platform

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Abstract: The Old World Screwworm Fly (OWSWF), *Chrysomya bezziana*, is an insect pest that is endemic to the tropical regions of Asia, the Middle East and Africa. The insect reproduces by laying its eggs in open wounds and mucus membranes of warm blooded mammals. Upon the hatching, the OWSWF larvae eat the living flesh of the host animal, causing injury, secondary infections and in extreme cases death. If this pest was introduced to the Australian mainland, it could have a devastating impact on the livestock industries within the northern regions of Australia. This work builds upon the existing research surrounding the OWSWF biological lifecycle and dispersal characteristics by developing a national-scale, high-resolution, agent-based model capable of simulating an invasion of Australia by the OWSWF. The challenge in designing large scale high-resolution models to run on personal computers is addressing performance issues.

We face this challenge by making use of *Graphics Processing Unit (GPU)* technologies, based around NVidia's *Compute Unified Device Architecture (CUDA)*, to simulate the lifecycle and dispersal of the OWSWF at the individual insect and cohort levels. This model combines agent-based logic, for simulating the OWSWF's lifecycle, with an efficient cellular-automata system to capture the spatial aspects of the OWSWF population's dispersal during a simulated invasion. The lifecycle and dispersal simulation is supported by an efficient system of main memory management which integrates bio-climatic data from a standard database management system for use within the model. The scheme adopted breaks this agent logic down into GPU-based functions, known as *kernels,* and uses the well-developed heterogeneous programming approach to distribute processing tasks between the *Central Processing Unit* (CPU) of the host machine and the CUDA device.

Analysis of the performance of the CUDA implementation reveals significant improvement in execution time when compared to an equivalent CPU-only based implementation, with results showing that the CUDA implementation's processing efficiency scales up well as the number of agents within the simulation increase.

Keywords: *Agent-Based Model, Graphics Processing Unit (GPU), Old World Screwworm Fly (Chrysomya bezziana), Lifecycle and Dispersal Simulation*

Optimal control of total chlorine and free ammonia levels in a chloraminated water distribution system

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Abstract: The ultimate goal of water utilities is to provide safe drinking water to consumers. One way of achieving this goal is by using disinfectants to remove harmful micro-organisms contained in drinking water. The most commonly used disinfectant in the drinking water treatment process throughout the world is chlorine. However, due to issues with disinfection by-products, chloramine has been used in place of chlorine by many water utilities. In a chloraminated water distribution system, not only total chlorine levels need to be controlled as in a chlorinated WDS, but also free ammonia levels in order to prevent nitrification. Therefore, there is significant interest in the development of an advisory control system for ammonia and chlorine dosing in a chloraminated system based on the relationships between the control variables and total chlorine and free ammonia levels at a downstream location of interest.

In this study, a model predictive control (MPC) system is developed for the Goldfield and Agricultural Water System (GAWS) east of Perth in Western Australia. The system is currently operated to maintain a constant ratio of chlorine to ammonia in the initial dose (i.e. 4.5:1). Hence there is only one control variable, namely the ammonia dosing rate at the upstream end of the system (Mundaring pump stations). As part of the control system, two artificial neural network (ANN) models are developed to model the relationships between the control variable and the controlled variables – the total chlorine and free ammonia levels at Goomalling pump station. These are forecast five days (i.e. 120 hours) in advance, as the travel time from Mundaring pump stations to the Goomalling pump station is approximately five days during the data collection period. A two-step process based on both mutual information (MI) and partial mutual information (PMI) is used to select appropriate inputs for both total chlorine and free ammonia models. In the first step, a control variable is selected based on MI as the first input for both total chlorine and free ammonia models; and in the second step, additional significant inputs are selected using a PMI based algorithm. As a result of this process, there are in total seven inputs selected for the total chlorine model and eight inputs selected for the free ammonia model. The developed total chlorine ANN model performs very well, with a validation Nash-Sutcliffe efficiency E of 0.84 and a validation root mean square error (RMSE) of 0.1320 mg/L; while the developed free ammonia ANN model performs slightly worse with a validation E of 0.62 and a validation RMSE of 0.0106 mg/L. A real-number coded genetic algorithm is then used to find the optimal ammonia dosing rate to achieve the required total chlorine and free ammonia levels at the modelling location.

The results of the control system show that the developed MPC system can control the total chlorine and free ammonia levels at Goomalling pump station to be close to their desired values by adjusting the ammonia dosing rates at Mundaring pump stations. The RMSE of the total chlorine model when controlled is 0.1482 mg/L, which is only slightly higher than the validation RMSE of the developed total chlorine forecasting model; and the RMSE of the free ammonia model when controlled is 0.0081 mg/L, which is lower than the validation RMSE of the developed free ammonia forecasting model. The performance of the MPC system in determining the control variable value is also satisfactory. Clear patterns can be observed in the predicted ammonia dosing rates. However, there are some points where the predicted ammonia dosing rates are outside the expected range. Consequently, further analysis based on the relative importance (RI) of ANN inputs is conducted to investigate the strength of the relationship between the control variable and the controlled variables. The results of this analysis show that the RI of the control variable is only 20.6% for the total chlorine model and 7.6% for the free ammonia model. This indicates that the errors in the MPC system in determining the control variable value are most likely due to the weak link between the control variable and the controlled variables, caused by a combination of the following factors: 1) the complexity of the system, 2) the relatively poor performance of the free ammonia model, and more importantly 3) the fact that the control variable was kept fairly constant during the data collection period and hence was not ideal for the development of statistical models and a control system.

Keywords: *Optimal control, chloramine, water distribution systems, water quality, artificial neural networks*

CFD modeling of airflows and contaminant transport in an aircraft cabin

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Abstract: There are an increasing number of passengers undertaking air travels on commercial airliners throughout the world annually. During the flights, passengers are possibly exposed to different contaminants such as bacterial and CO_2 from other passengers. As airliner cabins have high occupant density and flights can last from 1 to 20 hours, transport of contaminant could have serious impact on both passengers and aircraft crew. It is important to understand airflows and contaminant transport inside the aircraft cabin in order to reduce the negative impacts. Current aircraft cabin airflows can be analyzed by two different methods, experimental measurements and computer modeling. With the rapid increase in computer power, computer modeling is becoming more popular in study of aircraft cabin flows. Computational fluid dynamics (CFD) is the most used modeling approach since it is relatively inexpensive, fixable and able to obtain high level resolution results.

The main scope of this research is to develop a frame work to simulate airflows and trace contaminant transport in an aircraft cabin using CFD. The predicted airflows and contaminant concentration are then used to train an Artificial Intelligent (AI) system. This trained AI system will be able to trace back the possible source of the contaminant once the transmission of contaminant happens in the aircraft cabin, e.g. the severe acute respiratory syndrome (SARS) transmission in a flight in Hong Kong in 2003.

This paper reports the development of the CFD model of aircraft cabin flows and the transport of SARS in the cabin. In the project, the first milestone is to produce a section of an aircraft cabin of Airbus 320 using ANSYS/Design-Modeller. The cabin model includes half of the cabin with 7 rows of seats. The second milestone is to mesh the geometry using ANSYS/Meshing. The third milestone is to set up boundary conditions for both airflows and contaminant in ANSYS/CFX. The final objective is to solve the solutions in CFD and transfer the CFD results to an AI system developed by the authors.

Some CFD predictions of the airflow patterns and contaminant transport in the cabin are reported in the paper. It is found that the flow in the cabin is quit complex. There is a weak longitudinal flow that plays a significant role in the spread of contaminant in the cabin. Some preliminary results of the AI system are also presented in the paper.

Keywords: *CFD, contaminants, aircraft cabin, artificial intelligence*

Microsimulation of daily movement patterns in a British city

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Abstract: Social and demographic data about the composition of small geographic areas is readily available in many countries. For example, in the UK the Census of Population and Households generates counts for output areas which typically comprise only around 125 households. These data may be characterised as providing a picture of the *night-time* populations of different neighbourhoods which has been widely used in planning the delivery of services such as education and health care, and for strategic planning of land use or transportation.

However for many purposes the location of populations through the *day-time* may be of much greater significance. With regard to planning for emergencies whether natural or man-made in their origin, the actual location and distribution of people is rather more useful. A similar argument can be made for services such as policing and retail provision. In the work reported here, first steps have been taken to integrate two approaches to this problem. The first of these is characterized as *mapping* the population at different locations through the day. The second is referred to as *tracking* and seeks to follow the spatial movements of individuals in the population. The research demonstrates for a case study of the city of Leeds how a more complete picture emerges from the combination of these two approaches.

The Pop24/7 project at the University of Southampton has developed a *mapping* approach which seeks to exploit a number of directory sources to profile the changing composition of different locations through time. Thus pupil registers for instance can be used to provide reliable counts of children during the school day. In a similar way different layers, such as working populations or patients in hospitals and clinics can be accrued.

A limitation of the mapping approach is that it will rarely provide useful information about the social and demographic composition of day-time populations, and neither will it say anything about their spatial origins. An alternative method which has been developed at the University of Leeds is to create a microsimulation of small area night-time populations. In this process both small area statistics and anonymised individual records are used to generate synthetic individuals and households in accordance with the known aggregate characteristics of each neighbourhood. The movement patterns of these individuals – to schools, hospitals, workplaces - are then simulated in relation to the location of services and facilities using spatial interaction models. This approach may be thought of as a means for synthetic *tracking* of individual movement patterns which typically captures more detail at the origin than at the destination.

The combination of the mapping and tracking approaches introduces the 24/7 populations as detailed constraint vectors on the underlying interaction models. Alternatively this may be conceived of as a filtering process in which the daytime population counters are filled up with appropriate individuals from the surrounding areas. The procedure has been demonstrated with reference to a simulation of the city of Leeds. An assortment of performance indicators demonstrates variations in the composition of both origin (night) and destination (day) populations, and the patterns of interaction between them.

Through this combination it is possible to arrive at a superior end product which combines the best features of both methods. Tracking the purpose and spatial realisation of individual flows facilitates the representation of individual movement patterns within cities, and this opens up a range of further research opportunities in understanding the transmission of all kinds of tangible and intangible commodities around the city. The results of the case study simulation have been compared not just to census data but also to patterns in the use of the twitter social messaging service. Further work is still needed in order to provide a robust assessment of model performance.

Keywords: *Microsimulation, daytime population, spatial interaction model, mapping, tracking*

Bayesian model averaging for estimating non-stationary soil moisture data

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Abstract: Soil moisture content is largely dependent on the location-specific soil constituents and the current stage of the hydrological cycle. Due to the seasonal climatic effects, soil moisture estimation is a crucial step for agricultural drought monitoring and irrigation control. Large scale estimation can be performed using active or passive remote sensing techniques, which are usually regarded as being too coarse for farm-scale decision making. In the other hand, indirect in-situ measurements of soil water tension, moisture and temperature can be easily obtained and transmitted when using wireless sensor networks.

In this paper, we address the problem of the spatial and temporal uncertainty of soil moisture estimation from field measurements. A novel Bayesian Model Averaging (BMA) technique is used to correctly estimate the varying dynamics of soil moisture data at different locations and horizons. In particular, a hierarchical mixture of a Gaussian processes (GPs) is fitted to the noisy observed data and non-stationarity is assumed as a result of the heterogeneity of the different sampling times and locations. The model is tested with real data captured in the Maule region in Chile and results are compared to the standard stationary GP model.

Keywords: Bayesian model averaging, Gaussian processes, non-stationary data, soil moisture

Climate Change Effects on Sri Lankan Paddy Yield: An Initial Investigation Using Data Mining Algorithms

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Abstract: In recent times, climate change (CC) and its effects on key crops, such as rice, wheat and maize, have drawn significant research interest alongside population increase, economic growth and changing diet patterns, all of them considered as the driving forces influencing earth's food and water ecosystems. Despite recent technological advances, such as from improved plant breeds (*cultiva* or varieties) to irrigation systems, which have contributed towards improving the world's staple food production significantly, climate still remains as the key factor in agricultural productivity. Hence, understanding the effects of climate change on various staple food crops has become the utmost priority in many aspects especially, to overcome the threats to the world food security. As a result of this, many institutions concerned over related issues and research communities, in recent years, have turned their focus into modelling the phenomenon at various scales and levels. Contemporary research on modelling the climate change patterns in weather conditions and their effects is summarised. Existing crop forecasting models vary significantly in spatiotemporal scales and levels, the lowest being at the micro (e.g. the field or farm at specific days/weeks), and the highest at macro (e.g. regional /district, at months/years) or global, the crops being studied include, staple crops (maize, rice and wheat) and vineyards all using an array of variables characterised by 1) historic (using a multitude of sources, e.g. metrological, phenological, satellite imagery and wireless sensors at the micro scale, or 2) simulated data (www.ncdc.noaa.gov/oa/ncdc.html), both against observed yield

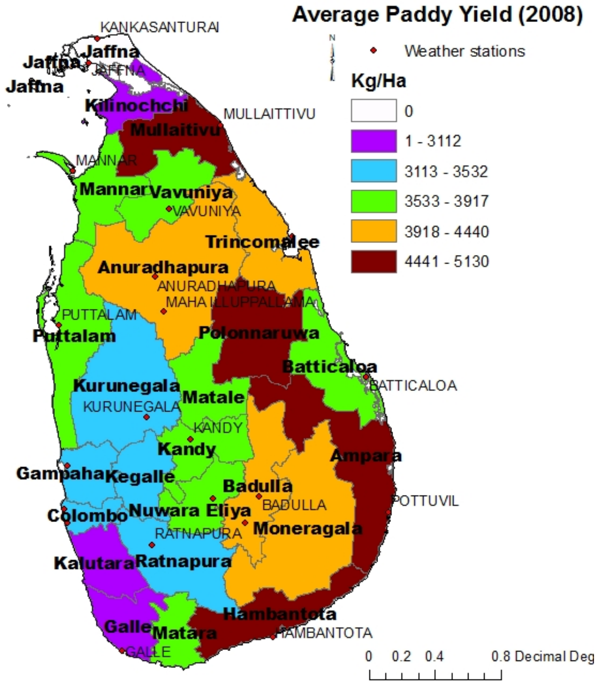

Figure 1. Paddy regions (in **bold** type) and weather stations (red spots). Source: www.statistics.gov.lk and www.ncdc.noaa.gov/cdoweb

In this context, the paper presents an initial investigation in which four data mining algorithms are explored to analyse the rice crop data in Sri Lankan administrative divisions, as an example study. Rice is the main staple food for Sri Lankans and paddy cultivation in the country dates back to as early as 800 BC. Presently, paddy is being cultivated as a wetland crop, either rain fed or irrigated. Lately, the country's estimated total land under cultivation is said to be approximately 708,000 Hectares cultivated in two seasons "Maha" and "Yala", that correspond to the country's two monsoons, North-east monsoon (from September to following March) South-west (from May to end of August). Paddy yield in various Sri Lankan divisions is presented in figure 1 based on 2008 average annual production obtained from www.statistics.gov.lk

The results of this investigation reveal interesting correlations between recent climate and paddy yield in nine regional divisions of Sri Lanka over "Yala" paddy season despite the gaps in the climate data that cannot be analysed using geostatistical or conventional methods due to the gaps in the data.

Keywords: *Soil nutrient, grapevine, geostatistical analysis*

Pixel clustering in spatial data mining; an example study with Kumeu wine region in New Zealand

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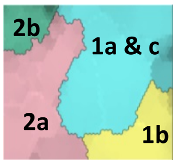
Abstract: This paper describes an approach to pixel clustering using self-organising map (SOM) techniques in order to identify environmental factors that influence grape quality. The study area is the Kumeu grape wine region of northern New Zealand (NZ). SOM methods first introduced by Kohonen in the late 1980s, are based on two layered feed forward artificial neural networks (ANNs) with an unsupervised training algorithm. They are useful in projecting multidimensional input data onto low dimensional displays while preserving the intrinsic properties in the raw data by which the detection of previously unknown knowledge in the form of patterns, structures and relationships is enhanced.



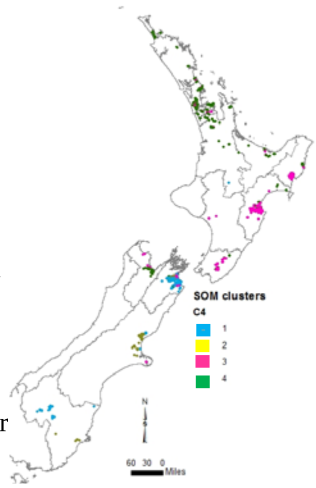


Figure 1a: SOM and NZ maps showing the SOM clusters of 437,888 NZ vineyard pixels, the major distinguishing attributes at this macro scale are: elevation, annual average- and minimum- temperatures, induration, drainage and monthly water ratio balance (figure 1b)

In modern day viticultural zoning approaches, factors that contribute to grape quality are typically categorised into three classes; *terrior* (climate, soil type, topography of a location), *cultiva* (the variety of the vine) and dependent factors such as berry quality indicators (e.g.: Brix and pH) and wine quality/market price.

Many modern viticulturists rely on expert knowledge and intuition to establish viticultural zones in conjunction with Geographic Information Systems (GIS) to further subdivide a wine region and vineyards into zones. The most common scale for such zoning has been the "*meso*" scale and the factors used for the characterisation of vineyards, varies extensively. The most adopted factors used for zoning are grapevine growth phenology (growing degree days (GDD), frost days/timing, berry ripening temperature range) for which comprehensive knowledge on local viticulture and wine quality is essential. Hence, for characterising vineyards from the *new world* or wine regions with insufficient knowledge for zoning is considered as a challenging task. For such instances, the SOM approach discussed in this paper provides a means to resolving a lack of extensive historical knowledge especially, when establishing zoning systems. The case study presented demonstrates the advantages of the SOM approach to identifying the ideal discerning attributes for zoning between and within vineyard/s using available geocoded digital data. The results of the SOM based clustering and data mining approach show that water deficit, elevation (along with hill shade and aspect) and annual average/minimum temperatures, are the main contributory factors for zoning vineyards in the Kumeu wine region at the *meso* scale. Interestingly, the elevation, annual average- and minimum-temperatures, induration, drainage and monthly water ratio balance are found to be the discerning factors at the macro conforming some of the currently used factors in NZ.

Cluster	pixel count	Ele vation	Ave Temp	A min Temp	A sol Radiation	Indu ratin	Exch Cation	Acid sol P	Che limitation	Age	Slope	Drainage	Wat BR	Water deficit
1a&c	177191	**128.59**	**12.04**	**1.57**	14.92	**3.11**	1.97	3.79	1.00	**1.87**	0.06	**4.34**	1.62	**219.95**
1b	93607	**62.37**	**11.62**	**1.09**	14.07	**3.31**	2.01	3.86	1.00	**1.16**	0.03	**4.88**	1.70	**208.26**
2a	127694	**36.85**	**13.35**	**3.20**	14.72	**1.23**	**2.21**	**2.46**	1.07	**1.37**	0.04	3.28	**1.76**	**179.55**
2b	39396	**93.84**	**13.74**	**4.59**	14.89	**2.28**	**1.42**	**1.62**	0.94	**1.71**	0.06	3.74	**2.67**	**54.10**
Total	**437888**													

Figure 1b: SOM cluster profiles, WatBR: monthly water balance ratio.

Keywords: *Self-organising map clustering, viticulture, infield variability*

Climate effects on grape production and quality at Kumeu, New Zealand

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Abstract: Grape quality and anticipated berry composition (Brix, flavour and aroma) significantly vary due to the variability in seasonal climatic and environmental conditions, such as soil and topography within vineyards. Such "*Meso*" climatic and "*terroir*" variations affect grapevine phenology (from bud formation to berry ripening stages). This in turn affects productivity, some instances extensively, in terms of total vine yield, grape bunch count, berry weight and composition even within a vineyard. Quantifying these effects on grape production and quality has been a challenging task as no detailed study has been performed at precision agricultural level for this vineyard located in Kumeu, New Zealand. This study investigates the influences of climate and soil components on the production of this vineyard using data gathered from 2011 to 2013.

Field monitoring conducted for the years 2011 and 2013 included soil sampling at strategic locations (figure 1), grape bunch and berry sampling for measuring bunch count, total weight and Brix (sugar) content in berry samples from the same specific sites for the two grape varieties (*Chardonnay* and *Pinot Noir*) planted in the vineyard. Unusually severe frost events were recorded in September 2012 in Kumeu, which affected the early developmental stages of the grapes significantly in many vineyards and this has resulted in observable decreases in productivity.

Preliminary results show a substantial difference between the crops harvested for the studied years, which is an indication of the damage caused by the abnormally severe frost experienced in the region in the beginning of the growing season. It warrants further investigation to understand the influences of topographic features which are either protective or damaging to the vine, especially the young buds.

The spatial analysis of topographic features, combined with plant production and soil nutrient composition identifies the damage prone areas. This information will be useful for any future investigations on possible mitigation strategies to protect vulnerable zones.

Keywords: *Soil nutrient, grapevine, geostatistical analysis: hot spot analysis, explanatory regression, ordinary least square regression.*

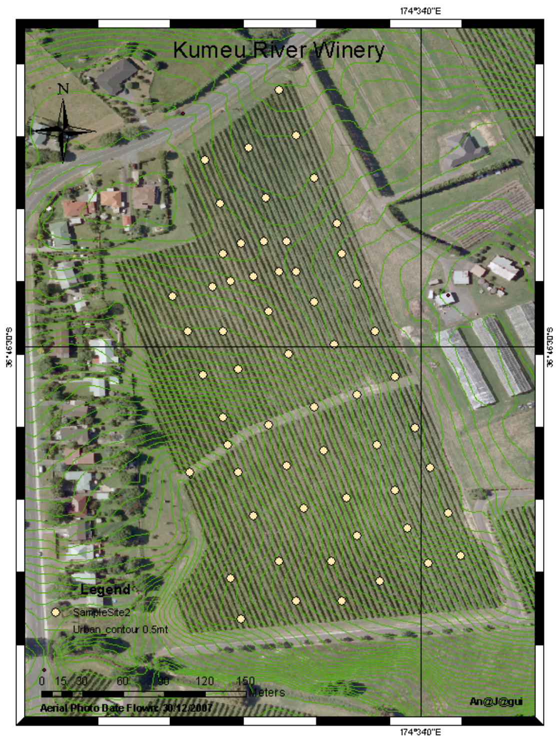

Figure 1. Map showing the soil, grape bunch and berry sampling sites from 2009-2013 Data on soil nutrients (Na, K, NO3 and pH), grape bunch and berry composition from these sites were analysed using geostatistical methods and the results show the subtle spatial variability within the vineyard in Kumeu (36°46′30″S 174°34′0″E), Auckland, New Zealand

A method and example system for managing provenance information in a heterogeneous process environment – a provenance architecture containing the Provenance Management System (PROMS)

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Abstract: For large distributed environmental information systems built for projects of national significance, such as eReefs and Bioregional Assessments, it is crucial they be able to capture information about their data processing in order to be able to trace the lineage of their data products. Policy and decision makers may need to know great detail about the processes that created data products in order to trust them as they influence crucial and high profile political decisions. Scientists may even need to be able to recreate modelling or data manipulation processes long after their original implementation in order to verify results.

There are a series of tools that help in this task: there is a W3C Recommendation for a 2nd generation provenance data model and Semantic Web ontology that has been developed by an international team of provenance researchers, known as PROV-O (Moreau and Missier, 2013). It is intended that it be used to represent the provenance of generic processes and can therefore be used as a common information format for projects that contain heterogeneous processes. Researchers in the CSIRO have developed a Persistent ID Service (PID) that helps to manage the identity of 'things' (information resources and representations of real world features) (Golodoniuc, 2013) for which, when those things are generated by human processes, provenance can be recorded. Provenance information can be very complex and different for every single process recorded, thus making storage difficult. Even though there are mechanisms (triplestores) built to store data of the PROV-O type, they are not massively scalable so we have used a recently popular, schema-less, databases that is able to store large collections of data 'documents' without forcing structural constraints on them. Additionally, the use of Linked Data through a variant of the Linked Data API (Epimorphics, 2013), also by CSIRO members, can be used to provide access to different forms, or views, of the 'things' stored. Putting these four developments together allows us to represent, manage, store and provide access to provenance data in novel ways. Implementing this is the focus of this paper.

A *provenance architecture* using the PROV-O ontology, PID Services, variant Linked Data APIs and several support services has been tested with several automated workflows, notably the Bureau of Meteorology's Australian Hydrological Geospatial Fabric's Contracted Catchments production workflow. We describe the development of this architecture and detail the componentry it uses – in particular the new Provenance Management System PROMS.

The methodology and architecture described here, more than the specific tools detailed, are this paper's contribution to large, multi-part, information systems' provenance handling so we present this information in order to demonstrate and approach, not to evangelise the use of a specific tool.

Keywords: *Provenance, data management, cultural change, semantic web, metadata*

The eReefs Information Architecture

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Abstract: eReefs is a large, multi-agency project that aims to deliver an information platform (eReefs-IP) which integrates existing and new data products. The eReefs IP will be used by both researchers and operational decision makers to better manage the Great Barrier Reef. Core to eReefs is the principle of interoperable systems whereby data generated and managed by a range of agencies such as the Queensland Government, the Bureau of Meteorology, AIMS and CSIRO, can be used together seamlessly.

The project runs for 5 years (2012 – 2017) and is implementing an information architecture for the eReefs-IP that has been developed from previous Australian and international natural resource distributed computing projects such as the Water Resource Observation Network, CUAHSI and INSPIRE. It is an NEII (National Environmental Information Infrastructure) demonstrator project and the lessons learned from eReefs will feed back in to the NEII and other NEII projects. In addition to delivering the eReefs-IP and new components for information architectures, eReefs is also extending the features and power of several water quality remote sensing and modelling systems.

eReefs is implementing a new distributed computing system approach to perform data service and support service tie-ins at the data provider level (data owner). This allows data providers to expose data set's data services in ways that enables them to be associated with the metadata and other services needed to ensure that it can be understood correctly. eReef contributions to information architectures include a new "orchestration service" that will help both the eReefs operators and data providers keep the eReefs community of systems running and growing over time. Additional architectural contribution is the first integrated use of a provenance service, PROMS, and extended use of the SISSVoc vocabulary service for data term definitions within data and metadata services.

This paper overviews the eReefs architecture at the highest level and provides a background outlining progression from earlier work to the current architecture. The new architectural concepts and components are discussed and some examples of implementation are given.

Keywords: *Great Barrier Reef, distributed computing, eReefs, WRON, National Plan for Environmental Information, data services, information architecture, Linked Data*

Integration of Wireless Sensor Network and Web Services

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Abstract: Wireless Sensor Networks (WSNs) integrated with web services are becoming common in widespread applications across the world. WSNs are developed in different application domains of sensor and user types, with each typically relying on its own metadata semantics, data format and software. There is a high demand for standardising access to sensor data via internet without having to use some complex and unknown protocol. Thus, Service Oriented Architecture (SOA) is one of the key paradigms that enables the deployment of services at large-scale over the internet domain and its integration with WSNs could open new pathways for novel applications and research. The sensor web enablement initiative (SWE) within the Open Geospatial Consortium (OGC) has released a set of open standards for interoperable interface specifications and (meta) data encodings for the real time integration of sensors and sensor networks into a web services architecture. This paper describes integration of WSNs into a SOA by proposing a web service proxy linkage of the low level sensor platform to the high level SWE sensorweb architecture to treat sensors in an interoperable, platform-independent and uniform way.

Keywords: *Wireless Sensor Networks, Vineyard monitoring, Service-Oriented Architecture*

Environmental modelling as a workflow supported by web services

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Abstract: As discussed in literature, one use of environmental models is to understand and manage natural resources. Models can be used, among other things, to examine the components and internal interactions of a system, predict management outcomes, reveal implications of assumptions, and enhance communication between researchers, managers, and stakeholders. It has been pointed out that modelling should become more iterative learning process with clearly defined development steps. At the same time, and in our experience, modelling is becoming more collaborative work carried out by geographically distributed teams using Internet-based tools.

Workflow is a widely used concept in scientific data analysis and processing, and in web-based information systems. A workflow is a formalization of a task or a job and a separation of data from processes, which are either manual or automatic activities. Web services are components of Internet-based information systems. They provide data or carry out well defined activities.

The goal of this work is, first to examine modelling as a task that consists of various activities that can be supported by web services, and second, what properties should a useful support systems for modelling have. A practical motivation for this work is the increasingly common scenario, where global changes motivate researchers and managers to understand and learn from each other and from the systems they study and manage. In our case the second author researches and manages a lake in Finland and in a project collaborates with researchers and managers of a lake in China. These two lakes show some similarities and face some similar pressures. The aim of the collaboration is to learn from each other and from model-based research and comparisons. In comparisons the same analysis workflow has to be repeated with both systems. Models promise a method for knowledge transfer but it is not easy to come up with shared conceptualizations.

The task of conceptualization has been separated into two stages, problem definition and system description. There are several methods for describing systems, for example stocks and flows, causal structures, object models, etc. Associated with these there are mapping tools for creating diagrams that communicate the description. A computational tool that implements an algorithm is typically used with such models. Finally, the conceptualization should help solving the problem with the model and the computation. Workflow modelling languages can be used to describe and plan workflows. Specific software, middleware that accesses concrete resources and tools, can be used to implement workflows.

In observation and measurement, and associated data analysis, very many separate pieces of knowledge are born in addition to data and meta data. This is an important phase and it would be valuable to be able to store the knowledge, and make it available and usable also later. These pieces of knowledge are usually initially conceptualizations (a state variable and how the measurement relates to that), relationships between variables (regression analyses), or annotations or descriptions attached to any of these. “Second order modelling” uses the knowledge collected in the first phase and prior knowledge. These models are also conceptualizations and relationships between concepts, but more complex and usually associated with the modelling methodology (simulation, Bayesian network, etc.).

A conclusion at this point of this work is that in modelling things seem to evolve from data to process and to data again, guided by increasing shared knowledge. The workflow systems to be developed need to be able to cope with such phenotype changes. Fine grained communication, for example annotations, seems to be important too.

Keywords: *Environmental modelling, Workflows, Web services*

Integrating scientific workflows with web services for data validation and provenance reporting

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Abstract: Scientific workflows aim to assist scientists in making their complex modelling tasks automated and repeatable. They allow scientists to run and re-run experiments, run modelling scenarios or apply complex procedures to datasets. Increasingly these datasets are provided externally as online resources or web processing services. This paper details methods for incorporating Web Services as outputs and inputs of scientific workflows using the linked data API.

The workflow engine Trident is built on .NET Windows Workflow Foundation which allows easy leveraging of a wide range of libraries and programming tools. Trident is a dedicated scientific workflow engine with comprehensive logging, fine-grained component versioning, provenance tracking, the visual representation of workflow status and it is designed to run on multiple machines.

We have created custom distributed computing components for Trident that allow workflows to remotely source and deliver data. This is done via RESTful Web Services using the Linked Data API as well as updating remote metadata registers of their run instances and products outputs. These products were created for and used by a specific project but have been contributed to a wider Trident development program known as Hydrologist's Workbench to allow them to be used in other projects.

In this paper we give an overview of a workflow as well as details of the distributed computing components created and how they may be repurposed for other workflows.

Keywords: *scientific workflow, Trident, provenance, PROMS, DIDS, web services*

Scientific workflows in a geographic portal for web-based spatial analysis

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Abstract: Our geographic portal, created in 2009, gives access to information collected during many years of scientific research. The information comes from the University of New Caledonia and its partners and includes field data, results of studies, analyses and scientific models on environmental, social and cultural issues. All the data concern New Caledonia, Vanuatu, Wallis and Futuna in the South Pacific.

The portal is based on a geographic server that implements OGC standards (Open Geospatial Consortium) on geographical information, including WMS (Web Map Service) and WFS (Web Feature Service), allowing information to be displayed on dynamic maps.

The purpose of this paper is to present the tools our portal provides to process specific scientific workflows on different topics. Unlike the static information that was previously available, the results of these workflows are not necessarily static and stored. Users can use the application with their own parameters, and can get the results of calculations in real time.

Two scientific projects are presented as examples of possible applications. The first is the assessment of the risk of fire start in New Caledonia. The increasing number of fires is causing substantial damage on the main land. A multidisciplinary team of scientists combined their knowledge to create a forecast model to estimate the risk of the start and spread of fires. The second project is about monitoring dredging for the creation of Vavouto harbor in New Caledonia.

The use of this tool in the two projects shows that incorporating workflows in a geographic portal is an efficient way to highlight and share their results. Incorporating workflows in such a framework makes it easier to interpret results, possibly by superimposing them on results of other workflows also calculated in real time or by using stored static data. This study underlines the importance of interoperability, as promoted by OGC.

Keywords: *Interoperability, OGC (Open Geospatial Consortium), dynamic maps*

Characterisation of different integration strategies in scientific workflows

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Abstract: Scientific workflow engines are powerful tools that allow for the composition of activities (computational components) into a reproducible, adaptable and well orchestrated whole – but the utility of any workflow is critically dependent on the way in which the activities are created. In this case the workflow engine being used is called Trident (a Microsoft Research application built on .NET WF). Trident compatible activities are able to be created in different ways, each method having its own trade-offs in areas such as performance, physical disk size, network bandwidth use, reproducibility, documentation and provenance tracking.

The Hydrologists Workbench (HWB) project investigated and created tools to support several different methods to wrap stand-alone code / programs into activities and this paper details and characterises those methods. Using a common data interface, design conventions and support tools, HWB is able to facilitate the construction of activities which exhibit the desirable characteristics of reproducibility and provenance tracking whilst at the same time not sacrificing workflow flexibility. By being able to create different activities using specific methods the workflow as a whole can be at the same time both flexible (allowing for model addition, subtraction or substitution) and reliable (easily able to verify correctness and provenance).

Four methods of wrapping code / programs are discussed and evaluated against a common set of criteria. These methods are programming the Activity manually, using a tool to wrap code / scripts, using a tool to wrap an entire application and using a tool to wrap a reference to an external application. Each of the four techniques is applicable under different circumstances and their strengths and weaknesses are discussed in regards to reproducibility, provenance, efficiency and usability.

Although requiring more initial effort, encapsulating a program in an Activity and placing it within a workflow can provide improvements to reproducibility, provenance and reuse. By making an informed decision around which technique to use when wrapping functionality it is possible to optimise reproducibility, provenance and usability in the workflow.

Keywords: *Workflows, Reproducibility, Provenance, Hydrologists Workbench (HWB), Project Trident*

Application of a scenario decision support solution for combined sewer systems

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Abstract: Climate change and changing rainfall patterns are expected to have impact on drainage and combined sewer systems. Designers and operators of such systems will have to prepare for greater uncertainties in the effectiveness of drainage systems in the future, and there are indications that the performance of investigated CSO (combined sewer overflow) tanks may suffer considerably when climate change is taken into account.

The EU FP7 research project SUDPLAN has developed a so called Scenario Management System (SMS), which integrates environmental modelling and software expertise, a system of standardised services and end user applications. The system is used to investigate alternatives of future developments while taking into consideration the long term projections of climate scenarios (air quality, hydrological conditions and intense rainfall) which are combined with local models. The SMS is based on the geo-spatial application suite CIDS which allows to build specific decision support systems on top of existing software components and data collections.

A list of publications regarding SUDPLAN can be found at www.sudplan.eu. For further information about the geospatial application framework CIDS, see www.cismet.de.

The study area for the CSO application is a catchment situated in Linz, Austria at the Danube River, covering approximately 900 km² in total. The area of downtown Linz with mainly combined sewers and 39 neighbour communes with combined and separate systems are drained to one central waste water treatment plant (WWTP). Several CSOs and CSO tanks are installed in the combined sewer system. From the estimated 115000 m³ of total storage volume in the system approximately 70000 m³ can be apportioned to three major storage tanks. The primary clarifiers at the WWTP are also used as CSO tanks during rainfall. The key question studied is whether the setup conforms to Austrian regulations today, but also in the future, taking into account climate change effects. The decision support system combines local SWMM5 model scenarios with climate-change enabled predictions produced by the SUDPLAN "Common Services". These services downscale today's rainfall time series according to a chosen regional climate change model. User can manipulate such scenarios in an integrated application environment which hides the complexity of models and data transfer.

Keywords: *Decision support systems, climate change, combined sewer systems*

An architecture for integrated crisis management simulation

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Abstract: The CRISMA project (www.crismaproject.eu) is a European Union funded project focusing on the simulation of multi-sectoral large scale crisis scenarios that have multi-dimensional effects on society and people. The project aims at the development of a framework to build use case specific tools which will allow decision-makers to cross-examine dynamic crisis scenario evolutions, to set action parameters of operational and strategic activities, and to visualise impacts and crisis evolvement. This will be achieved by providing a modular and open software framework to build planning and decision support systems for modelling and simulating realistic crisis scenarios and their possible consequences.

CRISMA applications simulate and analyse the development of a simulated "World" in a crisis management context. A *World* is defined as a coherent set of data, simulation models operating on this data and the model control parameters governing the activity of these models. A snapshot of the World, or *World State*, consists of all data related to a specific crisis simulation experiment. This includes a set of information to control simulation models operating on the World data as well as a set of condensed, representative and quantitative information that can be used for a qualitative assessment of a world state. The user can influence a crisis evolvement by changing control parameters of the simulation models. Every modification of a World State is considered a distinct decision point and eventually produces a new World State. This leads to a decision tree.

The architectural design approach uses several concepts from previous projects focusing on reference models, reference architectures and simulation-specific standards. For the CRISMA architecture, the project adopts certain common concepts that support a systematic architectural design process.

In order to demonstrate and validate the design, five pilot sites are used to provide experimentation for validation and testing of a wide range of crisis management situations (coastal floods, extreme weather conditions, geophysical hazards, multi-organisational and cross-border cooperation in crisis management, planning and training for resource management). Piloting will include multi-risk and domino effects.

The paper presents the business logic and key aspects of the CRISMA architecture. The work presented is work in progress, published during the design stage of the architecture. Implementation will be under way during the MODSIM 2013 conference.

Keywords: *Planning decision support systems, crisis management simulation, model integration*

Integrated Land Systems Modelling and Optimisation

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Abstract: The challenge of sustainable land management is to understand the involved ecosystems, their spatial variability, and the impact of human activities, and to 'configure' the landscape in the best possible way for sustaining natural resources and maximising ecosystem services. We introduce the Land Use Management Support System, which addresses system understanding by its environmental integrated modelling framework (EIMF) and land-use configuration by its multi-objective spatial optimisation component. LUMASS is built on free and open source software libraries and mainly targeted at processing raster data sets. The LUMASS EIMF is based on the Orfeo Tool Box (OTB) and the Insight Segmentation and Registration Toolkit (ITK). OTB/ITK provide advanced functionality for processing big n-dimensional raster data sets, such as sequential and multi-threaded processing. The LUMASS optimisation component is based on the mixed integer linear programming solver lp_solve and provides the optimisation of areal resource allocations. LUMASS supports read and write access of data sets via the GDAL/OGR library as well as storage and retrieval of big multi-dimensional raster data by rasdaman. Furthermore, rasdaman's Petascope component provides access to raster data via OGC-compliant web services, such as WCS, WCPS, WPS, and WMS. One of the main objectives of LUMASS is to allow non-programmers to develop spatially explicit system dynamics models. For that purpose, we developed a user interface for the interactive visual (i.e. icon-based) development of LUMASS models. The visualisation of spatial (raster and vector) data, attribute tables, and charts, is implemented based on Qt widgets provided as part of the Visualisation Toolkit (VTK). To support LUMASS model and optimisation applications on cluster environments, we also provide a LUMASS command line version ('lumassengine'). This also allows LUMASS to be run as a backend engine in distributed service-oriented architectures as well as being integrated into other component-based EIMF (e.g. OMS3, OpenMI), subject to the development of appropriate wrapper classes. The LUMASS EIMF is based on the ITK processing pipeline architecture and its fundamental components: data and algorithms (i.e. processes). They are augmented by iterable components that provide the capability to build dynamic and hierarchical processing pipelines. An iterable component may either host a single process component, or a chain (pipeline) of other model components to build a hierarchical structure of processing pipelines. Furthermore, iterable components allow the hosted components to be executed a number of times, thereby changing process parameter values with each iteration. Additionally, each model component is assigned to a user-specified time level. Execution order and data flow starts at the highest time level and descends to lower time levels. This allows users to implement models operating on different time scales and/or to control execution order for component initialisation purposes. Selected model components can be saved as XML-based files and re-used in other modelling exercises. For each component, general and component-specific properties, including the assigned values, are stored to build a complete blueprint of a model and its parameterisation. Used in conjunction with a version control system, such as git, it facilitates model management and governance, especially for revised model implementations. To enable the future development of different model views, e.g. as part of a web-application, as well as to enable the 'lumassengine' command line application, the graphical model representation as displayed in the user interface, is stored in a binary file format, and is completely separated from the model structure and parameterisation.

The free and open source Land Use Management Support System integrates spatial land systems modelling and multi-objective spatial optimisation. Its integrated modelling framework allows non-programmers to develop spatially explicit, hierarchical, and dynamic land system models using a visual programming environment. LUMASS makes integrated modelling available to modellers without requiring any programming skills. It supports the development of models operating on big data sets and different temporal scales, and supports the exchange and collaboration among modellers by facilitating the management, governance, and re-use of model components.

Keywords: *Spatially explicit system dynamics, Land systems modelling, Spatial optimisation, Integrated modelling framework, LUMASS*

Agent-based Modeling and Simulation Framework for Enhanced Project Schedules

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Abstract: Project schedules are essential elements in project planning. The common problem with them is that the initial project schedules are typically too rigid to reflect the surrounding uncertainties. For this reason we have developed an enhanced project schedule model whose design is simulation-based and incorporates a high degree of uncertainty that typically surrounds project developments. Enhanced project schedules (EPS) are dynamic and allow for pre-calculated beneficial interventions when uncertainties arise. This implies that they feature decision support too. The high degree of uncertainty is incorporated by providing, in addition to the initial project schedule, a set of remedial actions recommendations. Identifying the appropriate set of remedial actions that supports meeting project goals is challenging and carried out through simulation. To enhance the simulation processes that facilitate the design of the EPS and better reflect the uncertainty introduced by the human factor, we propose to use agent-based simulation, for which in this paper we provide the basic framework. The idea is to model tasks, teams and manager as agents with properties and interactions that would more realistically model their dynamic nature. We believe that this will add another dimension to how project schedules are viewed and analyzed. In addition, it will enable more realistic modeling of project schedules and allow for higher degree of dynamics in the generated enhanced project schedules. In this paper we formally define the framework for agent-based modeling and simulation of enhanced project schedules.

Keywords: *Agent-based Modeling and Simulation, Project Schedules, framework*

Comparative code verification using redundancy in a system for national scale hydrological modelling

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Abstract: The Australian Water Resources Assessment (AWRA) system (Stenson et al. 2011, van Dijk et al. 2011) was developed to support the production of national scale water resources assessments and accounts by the Australian Bureau of Meteorology. This paper examines a comparative verification process for identifying errors in the development of the river modelling component of the AWRA system.

The AWRA system is comprised of integrated modelling components representing the major parts of the terrestrial water balance, including landscape, river and groundwater processes. Several versions of each of these modelling components have been developed to support different use cases including: testing model improvements, optimizing model parameter sets, simple and stable deployment, high usability, and data model fusion. To meet these use cases there is some duplication in behavior across AWRA versions.

AWRA river modelling consists of separate calibration and operational systems. Across these systems equivalent data handling, execution sequencing, and model connectivity concepts are duplicated. Duplication can increase: the overhead maintaining synchronization, the logistics required to track duplicates, and the number of software bugs and conceptual errors introduced during development (Li 2006).

The duplication and complexity in AWRA increase the risk of bugs in code and in data pre-processing and management. Ensuring AWRA is numerically correct was an important part of development efforts. We describe a software verification technique that leverages the duplication present in AWRA to improve quality. For the purposes of this paper, verification of hydrological models is a set of processes that identify errors in software implementations and ensure the implementation matches the specification. Verification can reduce errors in software and thus can improve quality. Verification differs from model validation which assesses the performance of the model for its intended use. (Sargent 2005). A high level verification approach is function testing that checks the program against external specifications (Myers 2004). Freebairn et. al. (2005) describe a general purpose system that employs a variation of this technique for assessing the quality of a ported hydrological model. A similar strategy was used to create a comparative verification process to improve the quality of the AWRA river modelling systems.

Fundamental in the comparative verification process were comparative tests. These tests helped identify software bugs and issues related to the management of parameters and inputs in the operational and calibration implementations and were automated to provide continuous quality monitoring. The comparative tests compared modelled results checking that, for equivalent inputs, results matched across implementations. We found that, during the development of a modelling system, where there were duplicate components, errors in software structure, implementation, and specification could be identified and resolved through a comparative verification process.

Keywords*:* *Software testing, Hydrological modelling, Water resource assessments, Redundancy*

Development of complex scientific workflows: towards end-to-end workflows

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Abstract: The analysis of water planning options on environmental assets relies on combining mathematical models from several disciplines. The growing complexity of these modelling tasks increases the potential for mistakes and misinforming stakeholders and the public. Through better capture of provenance information (audit trails), scientific workflow tools improve the transparency of model interactions, which increases our confidence in the modelling results. However, scientific workflow tools can be complex to use and increase software development costs. Consequently, they have not had widespread adoption.

This paper examines progress toward end-to-end scientific workflows. These end-to-end workflows link heterogeneous data sources through to reports that evaluate ecosystem function. The aim of end-to-end workflows is to provide a system that can evolve as understanding progresses, data services come online and reporting requirements change.

The case study for this investigation is Little Rushy Swamp. Located in the Barmah forest near Echuca, Little Rushy Swamp supports a range of bird life. Over the past century, human regulation of the flows of the River Murray has changed the timing and frequency of flooding, which has caused the deterioration in Red Gum (*Eucalyptus camaldulensis*) health and wetland habitats. In recent years, the Australian Government has bought water licenses with the aim of improving the health of riparian ecosystems. The Government has used their water licenses to provide significant environmental flooding for the Barmah Forest. This case study shows how to link a model that characterises wetland hydrology in a way that supports ongoing reporting requirements that may be necessary for monitoring or management.

The workflow was designed using tools from the Hydrologists Workbench, which aims to ease the development of complex automated workflows in Trident. In the workflow, we use a simple water balance model to understand how the water level of Little Rushy Swamp varies under different climatic periods. The water balance model has daily inputs. The inputs to the model include data from text files, web feature services and outputs from other simple numerical models. The results are analysed using R-based statistics and ArcGIS-based geoprocessing. The workflow exports resulting images to Microsoft SharePoint using its web service interface. Using links, the images are incorporated into a Microsoft Word document. The Word document updates when the images on SharePoint update, providing an end-to-end workflow.

We find that the end-to-end workflow for Little Rushy Swamp addresses a number of challenges that exist in the integrated environmental modelling space. In particular, we establish that the workflow provides a valuable tool for incorporating new or revised datasets and methods. However, the benefits of such workflows are limited by the availability of web service data feeds that use consistent data formats. Further work should be directed towards handling of uncertainty by workflow systems.

Keywords: *Scientific Workflows, Integrated Water Resource Management*

Approaches to distributed execution of hydrologic models: methods for ensemble Monte Carlo risk modelling with and without workflows

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Abstract: Recent water reforms in Australia and the release of the Murray-Darling Basin Plan have been supported by climate models and detailed hydrological modelling including river system models. Sensitivity analysis of these river system models provides valuable insights into the often complex and non-linear relationships between uncertainty in input variables and parameters and model outputs. An understanding of these relationships is an important component of assessing the risks in the planning process.

However, a comprehensive sensitivity analysis is computationally intensive, requiring many thousands of simulations to examine a few parameters and may require months of computer time to complete. In this paper we consider a sensitivity analysis of a river system model using new and emergent technologies and discuss the merits of four methodologies for undertaking this analysis. In each case some new tools and techniques have been developed and these are applicable to sensitivity, uncertainty and error analysis of other simulation models.

The Murray-Darling basin is represented by a range of regional river models that are connected together to describe the entire basin. CSIRO recently calibrated regional *Source* models that, when combined, describe all of the Murray-Darling Basin. The Murrumbidgee regional model was selected from this project and subsequently simplified to reduce the runtime while still being representative of the system's behaviour. As part of a risk assessment, the sensitivity of this model was explored.

The sensitivity analysis examined uncertainty in inflows, rainfall, evaporation and groundwater/surface water interaction, via 100,000 simulations and the results can be found in Peeters *et. al.* (2013), submitted to this conference. The four methodologies considered to support this work are:

1. Running all 100,000 simulations on a single computer;
2. Running the simulations using several dedicated machines;
3. Running the simulations using ad-hoc computing resources; and
4. Multi-core execution, where runs are executed on a cluster.

Method 1 was the simplest, but requires the most computer time. Method 2 improved total runtime, but required dedicated computer resources. Method 3 gave reasonable runtimes, did not require dedicated resources, but did require constant monitoring and input. Method 4 was the most complex to configure, but provided very fast runtimes and automated input and output marshalling and cluster job creation and submission.

Methods 1 through 3 used Source's command line interface, while for method 4 the Source model was imported as a workflow activity into Project Trident via 'the Hydrologists Workbench'. Project Trident is a scientific workflow system developed by Microsoft Research and the Hydrologists Workbench is a suite of add-on tools for Trident developed by CSIRO's Water for a Healthy Country Flagship. Using Trident and the Hydrologists Workbench for sensitivity analysis allows the modeler to easily leverage available resources without requiring extensive or complex coding.

Keywords: *Sensitivity Analysis, multi-core execution, river system model*

A distributed stream-processing infrastructure for computational models

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Abstract: Decision support systems (DSS) that rely on time-sensitive information are demanding on the integration of computational models. Scientific models are commonly developed and tested with offline data coming from files and databases, but in a real-time DSS models have to deal with low-latency data streams, transmission faults and other imperfections. In practice, models need to process data from multiple data streams and various formats and require mechanisms to deal with delayed, missing and out-of-order data. It is desirable to handle data adaption, fault tolerance and other bookkeeping in a robust framework and allow domain experts to implement computational models in a mathematical language such as R, MATLAB or Fortran.

We present a platform that allows modellers to deploy R scripts and execute then in a distributed environment with online data. The platform is written in Java, dynamically sets up R sessions on distributed computers, manages the execution and deals with the input/output of models. An adapter strategy makes it possible to change data sources and formats without affecting the implementation of the computational model. In addition, fail-over mechanisms are implemented to guarantee processing in the face of a hardware or software fault.

In summary, the platform enables domain experts to implement concise computational models in a mathematical programming language (R), to test them offline in their accustomed environment and then to let them run online without modification in a fault-tolerant, distributed system. New models can therefore be easily added and the results are immediately usable by a real-time DSS.

Keywords: *real-time decision support, stream processing, online analysis, R integration, model execution, fault tolerance*

Creating workflows that execute external code bases that are under development

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Abstract: There is an increasing interest in the use of scientific workflows as a way to automate data management and model execution without requiring deep computing technical knowledge. Scientific workflows allow users to re-use previously developed code in multiple languages while providing repeatability and flexibility.

Additional complexity is introduced when scientific workflows use code that is still in development, especially when the code development is not linked to workflow development. In this paper, within the context of a particular workflow engine, we look at existing tools for code re-use and techniques to manage the complexity of working with rapidly changing code.

Hydrologist's Workbench (HWB) is a suite of tools, activities and recommendations built to support Microsoft's Project Trident, a scientific workflow engine. HWB contains several tools that assist in turning existing code into Trident Activities – atomic, composable, executable modules – via a process known as code "wrapping". The existing tools within HWB are designed to wrap code that is reasonably stable and unchanging and therefore these tools are insufficient for code that is subject to changes over time.

We have investigated techniques to minimise the effort required to turn code under active development into Activities and workflows. The techniques include: an agile methodology for workflow and code co-development; treating the code as a dataset itself; using an agreed interface; dynamically generating then executing scripted code; a simplified, template-based Activity generation tool and manual transliteration. Issues around testing, versioning, integration and communication are also discussed

Keywords: *scientific workflows, versioning, software design methodology*

Describing models on the web using OGC standards

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Abstract: Environmental decision support systems normally require a data processing workflow based on models to explore alternatives. The typical workflow to handle environmental modelling involves several steps covering data discovery, access, pre-processing, model execution and validation, concluded by result visualization. These time consuming steps are usually setup for a particular scenario and set of input data. Scientists normally create their models in specific languages such as R or MATLAB. A challenge is understanding the data model of the scientists and getting the data into the model. In general, scientists are also not able to make their models available as web services. To make scientific models that fuse sensor data fit better into a service-oriented architecture, a software framework called *Fusion4Decision* was developed. The software framework provides a standard interface to processing algorithms, the so-called *Fusors*. The term Fusor refers to a general fusion or processing of input data, including through a model based computation. A common fusor is the spatiotemporal interpolation of measurement data. The Fusor is written in any software code that can be integrated into a Java environment, such as MATLAB, R, Python, and C variants. This framework based on Open Geospatial Consortium (OGC) standards can make scientific models available as a web service with standardized interfaces.

The OGC services used in Fusion4Decision are: (a) *Sensor Observation Service (SOS)* to access sensor observations with queries filtering on the phenomenon (property) and the spatial and temporal domains of the observations, and (b) *Sensor Planning Service (SPS)* to parameterize and task (schedule and execute) assets such as sensors, sensor platforms (e.g. satellites), models or even persons (e.g. to conduct ex-situ measurements). The OGC information models *Observation & Measurement Model (O&M)* and *Sensor Model Language (SensorML)* also play a fundamental role.

The main operations of the SPS are DescribeTasking (to get the tasking parameters), GetFeasibility (to ascertain if the asset can be tasked with the given parameters) and Submit (to actually execute the task). During the execution the operations GetStatus and Cancel are available. In Fusion4Decision we apply the SPS to models and the model result(s) become new observations for a SOS, i.e. *the model is considered to be sensor* and its meta-data is described in OGC SensorML. The SPS operations are functionally richer than those of the Web Processing Service (WPS) that is also often used to wrap processing modules as a web service.

The formal description of the input and output arguments of the models in a language suitable both for scientists and client software is essential. The model description is encoded as a JSON object and consists of fields for the model name, a human readable descriptive text as well as formal descriptions of the inputs and outputs. The inputs and outputs allow for arrays of the basic variable types scalar, string, time, URL and file. Their description includes a) units of scalars, b) default, minimum and maximum values of scalars and optionally c) an annotation as a URI linking to an authoritative definition in an ontology. This covers the requirements of typical scientific models and also encourages the inclusion of comprehensive meta-data needed to convey full understanding of the model algorithm and its limitations. The JSON description of a model can be automatically translated into SensorML for use by the OGC services SOS and SPS.

The increasing proliferation of sources of geospatial data on the web as well as models to process the data and derive new information underlines the need for a standardised framework to better link data, models and their results. Standards of the Open Geospatial Consortium can be used to integrate data access and models into web services, thus being a step towards the Model Web in which scientists and decision makers can work together effectively. The paper proposes a simple way of describing the input and output arguments of a model using JSON. This JSON description can be readily understood and generated by model providers and also translated into the sensor description language SensorML. The latter is the basis for applying the sensor concept in the OGC standards SOS and SPS to models (“model as a sensor”). This approach bridges the gap between scientists and IT specialists.

Keywords: *Modelling, open geospatial standards, JSON, SensorML*

Modelling and Simulation of Tactile Sensing System of Fingers for Intelligent Robotic Manipulation Control

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Abstract: The robotic manipulation of delicate and sensitive objects is a process that necessitates tactile sensation, sensory feedback and grasping force control. To meet this requirement, work has been done towards the development of a Tactile Sensing System (TSS) for robotic manipulators, using tactile Force Sensing Resistor (FSR) technology. This work includes an experiment towards the determination of the behaviour of the underlying tactile FSR sensor, in response to inputs, the design of an Intelligent System to aid with grasping force control, the combination of hardware components into a Tactile Sensing System, the design of a practical grasping force control algorithm and a grasping force experiment, involving the application of the developed Force Feedback System.

In this work, the behaviour of the FSR, in response to an increasing applied force, has been shown. Furthermore, a Fuzzy Expert System Controller that aids with grasping force control has been designed. The systems design of the developed Tactile Sensing System and the comprehensive design of a practical grasping force control algorithm have also been demonstrated.

Distant robotic surgery and assessment on hand following trauma, as a result of disease or surgery, are of the future applications of this work.

Keywords: *Force Sensing Resistor, FSR, Tactile Sensing System, TSS, Fuzzy Expert System Controller, Grasping Force Control, Intelligent System, Modelling, Simulation, Manipulator, Tactile*

Intelligent Submersible Manipulator-Robot, Design, Modeling, Simulation and Motion Optimization for Maritime Robotic Research

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Abstract: With the recent technological advancement in submersible systems, the research and development of underwater manipulator robot is highly desirable. This paper focuses on comparing simulation versus real-time manipulator dynamics control, and comparison of intelligent underwater manipulator-robot for effective Ocean-based research, industrial and defense applications. Software package such as MATLAB is used to simulate the results of underwater manipulator performances and compare it with the real-time trials.

A mathematical model for underwater manipulator which encompasses deriving modified Denavit-Hartenberg parameters, computing all transformation matrices, deriving the forward kinematic and generating trajectory. Base on cubic polynomials, the manipulator trajectory is generated by using the joint angles and translation of each trajectory point. The result of manipulator performances is simulated by using SIMULINK. The manipulator simulation, which is aimed to analyze the movement of each arm, through the parameters of locations, velocity and torques are obtained. This paper also includes the comparison of manipulator-robot performance simulation with real-time trials. In order to measure the results of real-time, the Nintendo Wii remote is attached to manipulator to record the performances. The comparison can reveal the differences between simulation and real-time test in order to optimize for underwater manipulator.

Keywords: *submersible, intelligent, robot, underwater, manipulator, maritime, robotic, model, Ocean, simulate, motion optimization, modeling, simulation*

Advanced Oceanic Power Harvesting Systems for Autonomous Undersea Sensors

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Abstract: The technologies behind autonomous underwater sensory systems are continuously developing resulting in increasing capabilities and operating times. Power supply to these autonomous sensors is commonly facilitated via the use of primary alkaline cells, which causes limitations to operating periods. This study aimed to conduct a feasibility study into the application of small scale power generation to supplement power requirements for underwater autonomous sensory equipment.

An assessment of the availability and potential of various forms of energy which may be harvested within the oceanic environment resulted in wave energy being the most suitable form of harvestable energy. With waves as the chosen energy source, two wave energy harvesting devices, a surface buoy energy converter and a heaving point absorber were modelled and developed.

The surface buoy energy converter design aims to harvest energy from all six degrees of freedom induced from multidimensional dynamic conditions that exist on the surface of the ocean through the use of linear generators.

The heaving point absorber is a sub-surface operating device which incorporates a ball screw mechanism to translate vertical displacement of the waves to rotary motion for utilisation of a rotary generator.

Both devices require conversion of the generated power to a useable form for an underwater sensor. For each device an electrical system has been designed to ensure continuous power to the sensors. The status and performance of the devices can be monitored through the use of a data logger with remote communications.

Manufacture of prototype devices was undertaken to allow laboratory testing. The devices were tested for watertightness, proof of concept and power generation. These tests successfully proved both concepts and allowed for recommendations into further design improvements. The power production during the testing revealed modest power production of the surface buoy energy converter and a peak power production of approximately 25 Watts from the heaving point absorber.

Keywords: *Energy, Converter, Wave Energy Harvesting Simulation, Ocean, Sensors, Automation*

Maritime UAVs' Swarm Intelligent Robot Modelling and Simulation using Accurate SLAM method and Rao–Blackwellized Particle Filters

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Abstract: The objective of this research-study is to explore the performance of Rao-Blackwellized Particle Filters for accurate, simultaneous localization and mapping (SLAM), with Swarm Intelligent network of UAV Robots in oceanic environment.

SLAM is a method for Mobile-robots such as Maritime-UAVs Robots which could be valuable and effective to build-up a map on an unknown oceanic–air environment. In this aim, a variety of methods can be implemented and suggested by scientists. The Kalman Filter, Extended Kalman Filter, and Particle Filter are well known and popular algorithm techniques. Each of the named methods, are able to investigate on SLAM problem but may have some drawbacks, with working under some assumptions, that are not always true. As an example Extended Kalman filter estimates covariance matrix, that tends to underestimate the true covariance matrix, therefore it risks becoming inconsistent in the statistical sense.

Therefore, to get a good and accurate result, it is necessary to combine several methods together. That is included with Rao-Blackwellized method, with ability to construct Particle Filter and Extended Kalman Filter for SLAM scenarios. The Particle Filter technique is responsible for estimating Robot's pose as the Extended-Kalman-Filter estimates the landmarks.

Generally in marine applications UAVs are used for search and rescue mission(s), damage assessment, Maritime air environmental study and Maritime security reconnaissance which in most cases they need to cover an immense area of ocean(s). Therefore, time-wise using a single UAV is inefficient and there could be a risk of mission failure as a result of UAV's energy limitations as well as diagnostic problems. So, having a team of UAVs which each one can produce and follow its own map with cooperation with the others to satisfy mission goals would be much more efficient. The paper discusses the process of implementing, modelling and Matlab-simulation of the above techniques and shows the concept benefits in further studies of ocean-air Robotics application scenarios.

Keywords: *Rao-Blackwellised Particle Filter (RBPF), Swarm, Intelligent, FastSLAM, Simultaneous Localization and Mapping (SLAM), Unmanned Aerial Vehicle (UAV), Ocean, Maritime, and Robot*

Drag Coefficient Estimation Model to Simulate Dynamic Control of Autonomous Underwater Vehicle (AUV) Motion

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Abstract: A vehicle dynamics model is crucial for the design of control system for an autonomous underwater vehicle (AUV). However, it is not a simple task to determine the hydrodynamic forces especially the drag coefficient involved for any particular vehicle model. This paper describes a novel approach to approximate the drag coefficient of any given vehicle shapes and sizes using fourth order regression method. The vehicle is subjected to pre-conditioning phase, where it can be done with CFD modelling or subject to simple experimental test within an open environment. In the pre-conditioning phase, the vehicle is required to navigate freely around custom test environment to obtain the drag profile in real-time. With sufficient data, using the correlation 3D graph of drag coefficient and the change in angles, the drag profile of any given shape can be determined. The accuracy of the model is based on the frequency of trial runs, as well as the efficiency of the vehicle's on-board inertial navigation sensors. In this paper, the proposed approach is being demonstrated using ANSYS-CFX and the results obtained provide close approximation to the real drag coefficient. Therefore, the proposed novel approach is promising and can be used to find the drag coefficients for any given underwater vehicle at any conditions.

Keywords: *Autonomous Underwater Vehicle, Robotics, Hydrodynamics, CFD, System Identification, Modeling, Simulation, Control, Drag*

A Feasibility Study on the Design, Development and Operation of an Automated Oceanic Wave Surface Glider Robot

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Abstract: As oceanic research continues to grow for scientific and commercial purposes, demand for knowledge pertaining to the ocean continues to increase. This research investigates a Wave Glider that was developed by engineers for the purpose of collecting data from oceans. The Wave Glider is a novel two-body unmanned surface vehicle (USV). Compared to traditional unmanned surface vehicles, the Wave Glider has the unique advantage of long term navigation ability. With this advantage, the vehicle can complete missions which require long-term ocean trials.

This research project is focused on studying the feasibility of improving the design and operation of the Wave Glider and further developing its capabilities. To obtain real-time data, a scale model based on the original Wave Glider design has been manufactured. Improvement to the original design has already been achieved with regards to improving the stability of the wings. Based on a literature review, some concern was found over its robustness when trialing and this is addressed in this paper. Throughout this research, Computational Fluid Dynamics (CFD) analysis has been done on the Wave Glider to ensure optimum efficiency. Furthermore, CAD design of the scaled model has been reviewed to ensure success in manufacturing and operation. The Wave Glider model will be used to collect real time data for comparison with simulated data. Additional improvements included in the model will also be discussed.

Keywords: *Ocean, Wave, Surface, Glider Robot, Modeling, Numerical, Simulation, Automated, Optimise, Control*

Intelligent Condition Monitoring System (ICMS) for Unmanned Air Vehicle (UAV), Unmanned Surface Vehicle (USV) and Autonomous Underwater Vehicle (AUV), Robots: A Feasibility Study

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Abstract: An Intelligent Condition Monitoring System (ICMS) is important for different types of vehicles used to perform unmanned tasks. The main function of the ICMS is to ensure that the unmanned vehicle is in robust condition. In this paper, three main sections are built in ICMS. That is, structure health monitoring, power management and speed detection. For the structure monitoring, the pressure distribution of the vehicle is obtained by using CFD modelling. CFD is fluent software that contains the broad physical modelling capabilities needed to model flow, turbulence and heat transfer ranging from air flow over an aircraft wing to combustion in a furnace. In the test, the vehicle is required to work in regular condition, and the pressure distribution is obtained. The pressure distribution graph indicates the pressure at each part of the structure. Then, the part of the structure that needs to be monitored is determined. In relation to power management, the DS2788 as a battery chip constantly monitors the status of multiple cell batteries. These include the current, voltage, temperature and available capacity. It is applied for the detection remaining power in the battery. For the speed detection part, the RPM sensors are used to detect speed in real time and to make sure that the vehicle is running in the speed expected.

Keywords: *Intelligent, Sensors, Status Monitoring, Structure detection, Power Management, Speed Detection*

Small-Satellite Magnetorquer Attitude Control System Modelling and Simulation

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Abstract: The field of Ocean Robotics Engineering is expanding rapidly and there is demand for low cost, compact and light-weight small-satellites to communicate with remote ocean bound devices. This paper discusses the work carried out with the school's microsatellite group and focusses on the attitude control system which is vital for accurate satellite operation.

Establishing a mathematical model for micro-satellite attitude control system contains positioning sensors system, kinematic and dynamic concept of the attitude and statistic processing methods and so on.

In this dissertation, based on the Euler angle and Quaternion principles, we built the attitude kinematic model. By considering the magnetometers data and Fuzzy Control method the attitude estimation, was studied and investigated. The paper would also provide a brief investigation towards the modes of attitude control process and analysis. The result of unloading of a momentum wheel by magnetic rotation and precession damping is studied using Simulink. The control system model is included with relationship of three-axis motion simulation, to determine the pitch-channel and roll-yaw channel respectively. This process would define the stability controller problem of wheel unloading and protected mode for small-satellite stabilization.

Keywords: *Microsatellite, Small Satellite, Momentum wheel, Attitude determination, Attitude Control, Simulation, Modeling, Attitude stabilizationIntroduction, Fuzzy Logic, Euler angle, Quaternion*

A Many-on-Many Simulation Framework to Support the Development of Technology and Algorithms for Coordinated Munitions

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Abstract: In a world of increasingly network enabled weapons, it is advantageous to study how dynamically coordinated weapons can be employed in the battlespace. Coordinated weapons have the potential to improve the cost benefit performance of a given system of systems by either reducing the number and quality of sensors required, or increasing the effectiveness of a fixed system. This can be done by employing techniques such as simultaneous or staggered time-on-target, multi-directional attack and online target allocation and reallocation in response to a dynamic battlespace.

The study of such systems requires simulation models not just of individual weapon systems, but of weapon systems in the context of many-on-many engagements. Researchers working in this area will be concentrating on sensors and data fusion, mission planning and guidance and control algorithms. They require a simulation environment that supports rapid prototyping of concepts. They require a simulation environment in which it is easy to change the number and type of systems in a given engagement. Some researchers will be looking to incorporate simple techniques to existing detailed models while other researchers will wish to apply complex techniques to simple models. While many-on-many simulation frameworks exist, they are not typically easy to use and inhibit collaboration across different research institutions.

This paper proposes a simulation framework suitable for use in many-on-many engagements using Simulink. The framework supports a drag and drop interface of system components and mechanisms for exchanging user-defined custom data between entities. It has been designed to allow the incorporation of existing Simulink model libraries through a common interface. An example scenario of a coordinated aerial attack on a ground-based air defence system is presented.

Keywords: *Many-on-many, coordinated weapons, data fusion, simulink*

Self-Synchronisation in C2 Networks

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Abstract: Self-synchronisation is a key aspect of modern Command and Control (C2), and occurs when networked military units achieve the degree of alignment of their activities needed to accomplish their mission by exchanging information with each other, rather than being given detailed orders from above. The basic principles of self-synchronisation can be studied using models, and here we examine the ability of the "boids" of Reynolds (1987) to self-synchronise their velocity vectors within four-dimensional space.

As in past work, the average distance D in the network was the best predictor of the time required for agents to self-synchronise. For the case $D \geq 3$, 87% of the variance in synchronisation time was predicted by the power law $16.4\,D^{2.23}$. For the case $D < 3$ (consisting of Erdős-Rényi random networks), the synchronisation time peaked for networks of average degree 12. This results from the fact that densely connected subnetworks facilitate local self-synchronisation, but hinder global local self-synchronisation. This was confirmed by experiments on three highly connected networks, which showed that additional links within clusters actually slowed down self-synchronisation.

These results indicate that reducing the average distance in military communication networks is generally beneficial. However, within joint, combined, and coalition forces, improving the internal communications of individual components may actually be detrimental in terms of self-synchronisation of the overall force.

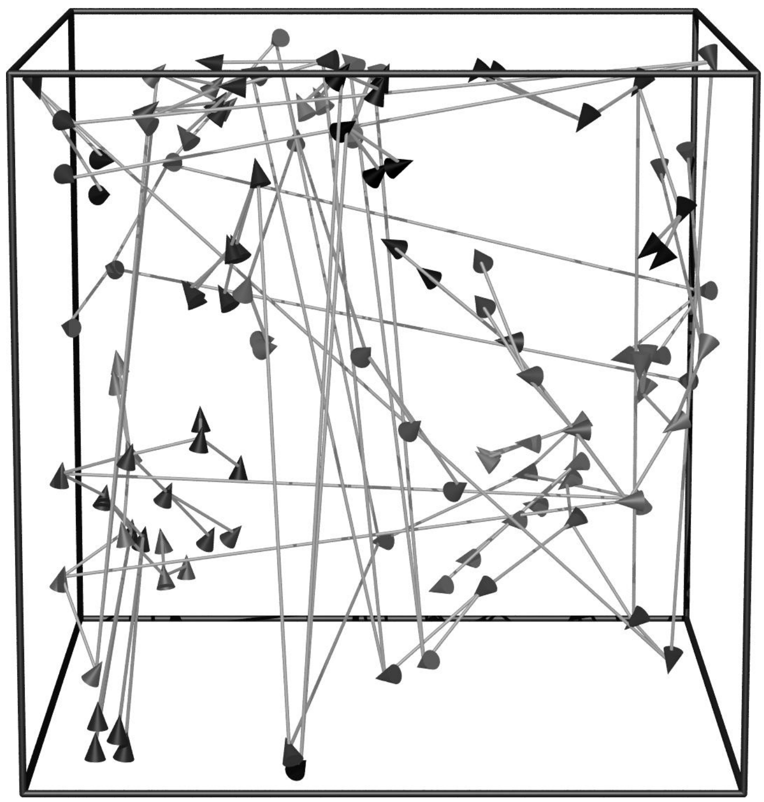

Figure (i). Early signs of self-synchronisation in a tree network. The direction together with the shade of grey of each cone indicates a four-dimensional velocity vector. Cones align with their neighbours in the network, but this local self-synchronisation has not yet produced global alignment.

Keywords: *Self-synchronisation, C2, networks, joint, coalition, boids*

Closing the Loop with the Close Action Environment

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Abstract: In this paper, I present the Close Action Environment (CAEn) Closed Loop (CAEnCL) wargame simulation that extends CAEn by adding a closed loop layer. An example of its use is presented to demonstrate the reactive branching ability of CAEnCL although the example is not based on a realistic military scenario. The CAEn simulated wargame is typically operated by human players in order to capture a real-time enacted Scheme of Manoeuvre (SoM). In military terms, the SoM defines a plan but a human-in-the-loop CAEn wargame only captures one enactment of the planned SoM. The captured SoM is usually replicated multiple times with different random seeds (which randomise many stochastic components of CAEn's models) to facilitate statistical comparisons between warfighting options under consideration. This approach introduces the potential for non-realistic actions by entities which are blindly following the captured SoM in the replicated simulation, and this inability to make reactive SoM changes limits the confidence that can be placed in the results from CAEn studies. For example, in the captured SoM, a tank may have been destroyed, causing the player to modify their SoM for the remainder of the wargame. However, later when the SoM is replicated, the tank was not destroyed in most replications but the decision to modify their strategy remains.

CAEn Closed Loop (CAEnCL) was developed to address this problem and also enhance the tools currently available to scenario developers and experimenters. CAEnCL connects to a CAEn server and mimics a human player reacting to the current situation by executing pre-defined orders once their trigger requirements are met. Thus, CAEnCL extends CAEn and gives entities the ability to deviate from a generic SoM in response to situational changes.

The scenario developer is provided with the tools to build a complex scenario which includes multiple branches via a Graphical User Interface (GUI). An intricate communications model is also provided, capable of simulating many concurrent communication architectures, facilitating the realistic exchange of information between battlefield entities and resulting in more informed decision making.

A common use of CAEn involves recording two SoMs under different experimental conditions from two human-in-the-loop wargames and comparing the results. Conducting the experiment in this way introduces human variability. CAEnCL assists the experimenter, increasing the confidence in CAEn results by simulating realistic reactions to the current environment. For CAEn human-in-the-loop experiments, where the experimental variable of interest cannot be changed without recording the SoM again, CAEnCL helps the experimenter remove human variability.

In this paper, CAEn and closed loop wargame simulations are introduced followed by an overview of CAEnCL. Greater detail on how CAEnCL works including ordersets, orders, triggers and the communications model is presented. Finally, an example scenario and an analysis of branching is presented to show the enhanced utility of CAEnCL.

Keywords: *CAEn, closed loop simulation, constructive simulation, wargaming, combat simulation*

Management of Interdependencies in Defence Capability Portfolio

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Abstract: The aim of this study is the development of methods and tools for analysis and management of interdependencies in the Defence capability portfolio. Capability development in Defence aims to develop and maintain the most operationally effective and cost-efficient mix of capabilities required to achieve Government's strategic objectives (*Defence Capability Development Handbook*, 2012). The fiscal and other resource constraints mean that wise choices have to be made regarding capital and resource investments. In a traditional project management, success of an individual project is usually assessed against its own unique set of goals. However, in the large Defence enterprise, multiple projects are underway at the same time, which have many direct and indirect interdependencies. Therefore, effective definition, development, and implementation of the Defence capability projects are practically impossible without taking into account all project interdependencies and portfolio approach to defence capability development is desirable.

In this paper, we start by reviewing international best practices in the application of Project Portfolio Management (PPM) in the Defence context, including multi-criteria decision analysis and portfolio optimisation techniques. PPM could provide a better way for achieving an effective and balanced Defence Capability Portfolio. Analogous to Program Management, referring to managing a set of projects, Portfolio Management refers to managing a set of related programs within an organisation. Defence Capability Portfolio includes all of the capability-related projects and programs within the Defence enterprise, including planned and ongoing capability development projects from the various domains including air, maritime and land. Portfolio Management does not represent one particular method; it is rather a general approach within which many alternative methods exist.

Development of a consistent framework for the interdependencies is required as various Defence stakeholders have very different and often conflicting views on the nature and type of project interdependencies. Following the summary of best practices, we present our work on identifying and categorising project interdependencies in the Defence Capability Portfolio. We use the international best practices to identify a set of canonical project interdependencies which are most relevant to Defence capability development. We find that interdependencies between the Defence capability projects fall into one of the four following major categories: benefit interdependency, resource interdependency, operational interdependency and risk interdependency. Collectively, the above categories cover the spectrum of capability, cost and schedule interdependencies in Defence capability development.

We apply network analysis techniques to identify important project clusters and also to visualise project interdependencies. The projects are represented as network nodes and interdependencies are modelled as links. In the last two decades many empirical and analytical methods, techniques and tools have been developed to aid network analysis. These tools have provided numerous measures and algorithms that have proved to be very useful in studying network properties and behaviour, both static and dynamic. We utilise a sample set of techniques to analyse a sample network of projects.

We also present a prototype interactive tool for automated project rescheduling in the Defence Capability Plan (DCP) which takes into account critical interdependencies between project delivery milestones. The DCP rescheduling problem is formulated as an iterative sequence of Mixed Integer Linear Programs (MILP) which is used to determine a feasible schedule that satisfies all budget constraints whilst satisfying the interdependency constraints.

Keywords: *Defence Capability Portfolio, Portfolio Management, Project Interdependencies, Network Analysis, Project Scheduling*

Assessing the Military Impact of Capability Enhancement with Netlogo using the Falklands War as a Case-Study

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Abstract: Military operations generating joint effects present significant complexity, often being comprised of large numbers of varied actors with competing goals operating across varied complex environments. This gives rise to the need to consider large combination sets when applying analytic techniques. The combination of modern, flexible and powerful agent-based models, computational search techniques and modern cluster computing promise faster, more efficient and accessible representation and exploration of parameter spaces and fitness landscapes of complex problems. We wish to apply these techniques to joint operations analysis, concept exploration and testing, joint capability analysis, emerging technology assessment and force structure analysis to enhance the quality and completeness of military planning.

Netlogo is a widely used agent-based modelling environment. This paper explores the feasibility of using Netlogo to build agent-based models to support operations analysis. A key objective of this study is to investigate the suitability and capability of Netlogo to represent military scenarios and to establish validity by way of reproducing historically documented operational dynamics and outcomes. To accomplish this, a scenario was constructed based on the air battles that occurred throughout the 21st of May 1982 in the Falklands War. This scenario is appropriate as the conflict is well documented and amenable to analysis. A historical 'baseline' case was successfully modeled, analysed and validated against historical analysis, and a number of technology insertion cases have been modeled. The modelling allowed for the generation of quantitative metrics that compare how operational effectiveness and operational risk were affected by capability enhancement.

Keywords: *Netlogo, agent-based, operations analysis*

Individual Psychological Conflict within Social Group Dynamics

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Abstract: In this paper we investigate the implications of a conceptual-model for competition in decision-making, where as a result psychological conflict might arise for either individuals or social groups of artificial embodied agents. We propose a *nonlinear dynamical system with control* approach to compose a *socio–cognio–physical* model of embodied agents in our *crowd dynamics simulator*, with a Lewin field theoretic model of cognition, which in principal is capable of being applied to a wide range of concrete problems. For instance, elsewhere in this conference Millikan et al. (2013) applies these Lewinian principles to the problem of military suppression for dismounted infantry. Wong (2012) has also used these constructs in a study on crowd reactions to Non-Lethal-Weapons.

Of Lewin's nine constructs of field-theory we will largely be concerned with the constructs of *conflict* (approach-avoid psychological conflict amongst the typology of Lewinian psychological conflicts) *position, locomotion, force, goal* and will briefly touch on *power* (inducing psychological forces on others to cause them to act; e.g. command). In particular we present a brief recount of psychological conflict simulation models, together with a qualitative analysis of conflicting attractor behaviour. Further, the consequences of the field shape have been considered for a simple nonlinear model of attraction and repulsion. There are a number of reasons why consideration of complex nonlinearity is required for modelling embodied cognition. Among them, we note, it is not possible to look at individual behaviours in complete isolation (classic controlled psychology experiments), without breaking the whole web of interdependencies (Lewin, 1997, pp 383-410).

Methods of investigation for general social dynamics have been reviewed by Castellano et al. (2009) as being entropic, topological, *dynamical systems* (DS) and *agent based models* (ABM). Castellano's statistical-physics based approach, however, fails to identify explicit individual entity control or self-regulation as an important element; see (Conant and Ashby, 1970). Therefore the minimum modelling capability of an embodied agent must be effectively the equivalent of a *dynamical system with control* (DSC), irrespective of whether the model implementation is actually an ABM or alternatively a nonlinear DS with each agent possessing a cybernetic controller for its cognitive model.

While there are other computational models of cognition ranging from the disembodied to the social, see (Sun, 2008) for summaries on SOAR, ACT-R, CLARION, they cannot cope with the change in scale of modelling fidelity, because, in our view, they do not see their psychological and physical worlds in terms of fundamental forces, be they physical, psychological or social, in some appropriate geometrical space. Neither can they seamlessly recurse between a representation of the psychological-present moment and either the psychological-past or a projected psychological-future, or indeed both; see (Ivancevic and Johnson, 2012). They also fail to represent an explicit model of control (Johnson et al., 2011), breaking Ashby's dictum that *"Every good regulator of a system must be a model of that system"* (Conant and Ashby, 1970).

In brief then, our broad problem is to find predictive embodied models of cognition with explicit models of control or self-regulation. We are following Millikan et al. (2011), who have suggested that understanding the detailed behaviour of conceptual models is a key part of a wider effort toward holistic societal modelling. In particular, the conceptual model under investigation here is one of nonlinear psychological competition in decision-making, where the competition may lead to psychological conflict and vacillatory behaviour or stable equilibria. The specific question we will examine in this study is the effect of the dynamic spatio-temporal field-strength shape on the behaviour of artificial embodied-agents. Following a standard approach used in theoretical-physics we will progressively examine field-strengths which vary linearly, then cubically and finally quintically. Further, appropriate control geometries and are being sought, following Lewin (1936), to represent the dynamics of individual agents and social-groups decision making interactions.

Keywords: *Crowd dynamics, Lewin's field-theory, Psychological approach-avoid conflict*

Computer-based Simulation of the Wayamba Unmanned Underwater Vehicle

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Abstract: Unmanned systems continue to generate significant interest from a wide range of entities, including researchers, vehicle operators and the general public. Compared to legacy manned platforms, unmanned systems have the potential to provide increased and persistent situational awareness whilst exposing operators to less risk. Although unmanned systems may provide novel capabilities, they often require significant manpower to operate and can also be expensive to develop, operate and sustain. Computer-based modelling and simulation provides a cost effective means to develop and evaluate appropriate designs and the concepts of operations that underlie the proficient tactical use of unmanned systems. It is paramount that accurate models are utilised to ensure simulations produce meaningful results, so that designs can be adapted as early as possible to reduce costs. Moreover, to reduce complexity and lead times of simulation development, developers can exploit an increasing number of existing tools. These include Commercial Off The Shelf (COTS) software to assist with the development of motion models, though the abstraction of such tools may limit the physical understanding of the vehicle that may be gained from deriving equations of motion from first principles. State-of-the-art virtual environment technologies allow for the creation of realistic modelling environments, in which numerous vehicle motion and sensor models can be integrated within a single simulation facility.

This paper outlines the results of research undertaken at the Defence Science and Technology Organisation (DSTO) towards the development of a computer-based simulation facility for the Wayamba Unmanned Underwater Vehicle (UUV) project. The simulation suite includes a higher level COTS UUV simulation system called AUVSim that can be used as a virtual environment for Hardware-In-the-Loop (HIL) simulations, and a DSTO-developed, MATLAB®-based model of the vehicle, for investigating low-level vehicle dynamics and performance. The low-level vehicle model was formulated using the "component build up method" and does not require the determination of hydrodynamic derivatives, reducing both the development time and underlying complexity of the model. Its derivation involves decomposing the vehicle into its basic elements, including the hull, conning tower, bowplane control surfaces, fixed sternplanes and the propulsion system represented by a pair of aft thrusters. At this stage, the model does not incorporate the vehicle's through body tunnel thrusters. The AUVSim vehicle model is constructed using a similar "component build up method", but the underlying equations of motion that govern the resulting vehicle model are not accessible to the user. This COTS "black box" simulation model has a shorter development time than the low-level model and is best suited to investigating the effect of vehicle hardware configuration changes and their influence on the vehicle's ability to conduct various manoeuvres. The low-level vehicle model is fully adaptable and can be used to investigate a wider range of operating conditions for the vehicle, including new actuator types. The representativeness of both the low-level and COTS model is established by comparing relevant simulation results with real vehicle data obtained from field trials. To facilitate further development and improve the fidelity of these simulation models, outstanding areas of research and directions for future work are also provided.

Keywords: *Unmanned underwater vehicles, modelling, simulation, autonomy*

Testing various backtracking algorithms in airborne maritime surveillance modelling

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Abstract: Maritime surveillance is an important task for the Australian Defence Force. Australia has a vast coastline, many offshore territories and extensive offshore resources in fisheries, oil and gas. There is a need to monitor these areas for illegal activities a need met by ships from the Royal Australian Navy and aircraft from the Royal Australian Air Force (RAAF) and Border Protection Command (BPC).

In a typical airborne maritime surveillance scenario, an aircraft will fly in a specified Area of Interest (AI) – in this case a corridor – and seek to detect and classify all the ships (i.e. a 'classify-all' search) that move up and down the corridor. In this particular instance a corridor search of a shipping lane is considered, where an aircraft flies up the corridor as ships move up and down. Security of shipping lanes is of vital interest to nations, especially maritime nations such as Australia. Major shipping lanes occur to Australia's north, especially around Singapore. Merchant and cargo ships carry trade from the Suez Canal and Persian Gulf via the Straits of Malacca and on to North Asian countries such as China, Japan and Korea. Much of Australia's exports such as iron ore and coal pass through this region.

In previous maritime surveillance modelling work, it was found that an aircraft may struggle to classify all targets in an AI in the available time, due to the high ship density or the lack of endurance of the aircraft. Either the aircraft does not complete the search of the whole AI or not all targets are classified. This work considers ways to address this scenario through testing various 'backtracking' algorithms. These backtracking algorithms allow the aircraft to consider classifying ships that are detected behind the aircraft (such as ships advancing through the shipping lane) while still ensuring that the whole area is searched.

The backtracking algorithms tested here can be grouped into four categories:

- *On/off.* Backtracking is either unconstrained (where the aircraft classifies the next ship regardless of position) or ignored (so the aircraft only ever classifies ships ahead of it).
- *Time-based.* The aircraft backtracks depending on its *pro rata* progress through the AI. For example, if the aircraft has reached half of its maximum endurance, the aircraft may be excluded from searching the first half of the corridor.
- *Classification-based.* Here the aircraft is allowed to classify a maximum number of ships behind it, before being compelled to classify at least a minimum number ahead of it.
- *Dynamic.* In this case, the decision to classify a ship behind the aircraft is determined using probabilities. If the aircraft is ahead of where it needs to be in the AI based on the time remaining, there is a greater probability that it will be permitted to classify a ship behind it. The probability depends how far 'ahead of schedule' it is. If it is behind, it will be forced to move forwards. The probability decreases to zero by the end of the mission to force the aircraft to fully cover the area.

A simulation model is used to conduct the analysis for a generic helicopter searching a corridor 250 nautical miles long and of varying widths. Ships travel at speeds of 15 knots or 25 knots up or down the corridor and various densities are considered. A Nearest Neighbour search is used for simplicity to test the various backtracking options. The Measures of Effectiveness (MOEs) are the percentage of ships classified and the percentage of the area searched. It is found that for corridors of narrow width or low numbers of ships, techniques favouring greater backtracking perform best. Here the classify-all search is achievable, as there is time available to explore the area given the lower ship density. In higher-density and wider corridors, where the need to divert is greater, there is less time available for such diversions. In these cases, the dynamic backtracking and linear time-based backtracking options are best, in that they ensure that the search is completed and achieve the highest classifications given that pre-condition. Both these techniques track the *pro rata* progress of the aircraft through the corridor, thus helping to ensure that the search is completed. Other options may achieve more classifications but not complete the search.

Keywords: *Maritime surveillance modelling, simulation, heuristics, backtracking, analysis*

A Multi-Agent System for Investigating Course of Action Planning

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Abstract: Autonomous systems are of growing interest to Defence. As robotics, artificial intelligence (AI) and software development grow in maturity, it is anticipated that the shift from automation to autonomy will require a revolutionary advancement in Command and Control. A significant and challenging aspect of Command and Control is Resource Management. To highlight and investigate Command and Control concerns we have developed the Command and Control Resource Management (C2RM) project.

In the C2RM simulation, two competing teams must develop and execute a Course of Action according to a given scenario with varying goals, such as the delivery of essential cargo to a randomly selected location in the opponent's territory. Each team is arranged in an agent hierarchy to manage the communication overhead and reduce the state-action space. At the top of the hierarchy, the higher level planner determines high-level/composite tasks such as patrolling an area or clearing a path. These composite tasks are passed to an auction system that determines the best agent or team of agents to perform the task (see Figure 1). The agent(s) then perform their own planning to fulfill the composite task by breaking it down into atomic actions. This allows the higher-level planner to plan at a more abstract level, ignoring details of action execution. Various machine learning and planning techniques will be explored to implement the higher level planner. These planners can be tested against each other in the C2RM simulation, as well as against human opponents. Our aim is to develop an AI planner that can defeat a human planner.

Two heuristic planners have been developed thus far, one that moves all agents directly to the goal and engages any encountered enemies, and one that avoids enemies whenever possible. Initial results of the two heuristic planners show that the aggressive planner is effective against opponents with vulnerable defenses but takes significant risks which can lead to early failure. In contrast, the passive planner will achieve its goal given enough time but it can be overly risk-averse and can lose to more reactive opponents.

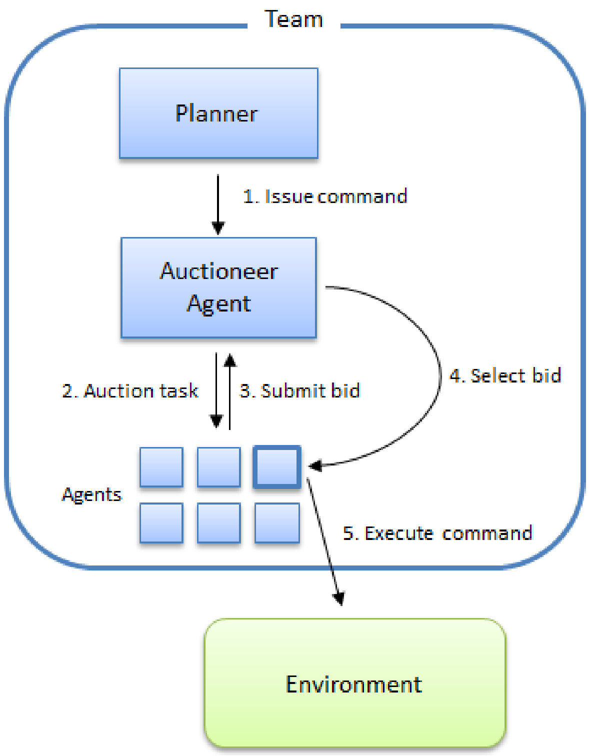

Figure 1. Agent hierarchy and task allocation in the C2RM simulation.

These basic planners were developed to provide a baseline for testing more advanced planning methods. One such method will involve the use of the Monte Carlo planner to learn effective strategies. This would entail running many simulations, executing random actions at different stages of the simulation, and recording the outcomes. The results would allow the planner to determine the most effective actions in forming a full strategy. Using the C2RM simulation, the Monte Carlo planner will be benchmarked against the heuristic planner in order to assess its effectiveness as a planning system. Future work includes developing the Monte Carlo planner as well as exploring additional techniques such as co-evolutionary algorithms and reinforcement learning.

Keywords: *Multi-Agent Systems, Task Allocation, Course Of Action Planning*

Methods and Models in Preparing Weapon-Target Interaction Data for Combat Simulations

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Abstract: Combat simulations are part of a suite of tools used by Defence Science and Technology Organisation (DSTO) to support Army decision makers, allowing analysis of the effects of changes in equipment, tactics or force structure. In order to represent combat effectively, these tools require enormous amounts of input data, which cannot be gained from empirical sources. This input data must cover aspects such as detection and identification of targets, behavioral decision making, basic system capabilities and weapon/target interactions. This data is represented within these combat simulations as lookup tables, from which an appropriate result, or probability of a result, is selected.

Our approach (Mazonka, 2012) seeks to provide fit-for-purpose vulnerability and lethality data to allow these simulations to adjudicate the outcomes of combat. This approach takes simple physical data from weapon and target systems and applies physics models to determine the probabilistic results of their interactions. We are cognisant of a number of limitations: the paucity of available empirical data, short lead times for data requirements and a requirement for an extremely broad set of interaction data, at the expense of depth.

In this paper we briefly describe our solutions to problems of armour penetration, probability propagation and blast effects, along with methods for converting generic result data such as vehicle probability of kill models into simulation-specific input data. These solutions are presented as a series of limited, low level methods, which illustrate some of the challenges inherent in generating fit-for-purpose combat simulation data.

Keywords: *Combat Simulation, Performance Modeling, Data Generation, Applied Mathematics*

Discrete event simulation of hydrographic launch and recovery operations

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Abstract: A large portion of Australia's national hydrographic survey and charting programme is carried out by the Australian Hydrographic Service of the Royal Australian Navy. Hydrographic survey involves using sonar or other means to measure the depth of the sea floor and to detect features such as shipwrecks or large rocks. For the most part, this is carried out through the use of sonar systems attached to a large manned vessel (such as hull mounted or towed systems) but emerging technology will allow more surveys to be carried out using deployable, unmanned vehicles (UxVs).

This new technological paradigm raises a number of questions with respect to the operation of multiple UxVs from a mother ship. Specifically:

- What is the maximum number of UxVs that a single vessel can operate effectively in tandem?
- How effective is the addition of each additional UxV?
- In the case that the deploying vessel also has organic sensors, how is the overall rate of effort affected by having to deploy and recover UxVs?
- What effect do UxV parameters such as endurance, failure rate, and deployment and recovery times have on the overall rate of effort?

In this study we investigated UxV operational issues by developing a discrete event simulation (DES) to numerically explore the parameter-space with the aim of discovering lessons able to be applied to potential future acquisition decisions. It is hoped that this may lead to higher fidelity modelling which focuses on the important system parameters. In this study we used the *MATLAB and Simulink* DES package, *SimEvents*. The *Simulink* graphical programming language allowed fast model development and analysis of results.

As this is the first stage in the acquisition of a theoretical system, this study was primarily focused on understanding the impact various parameters have on effectiveness of a simplified model. This included using a regression analysis. The parameters that were studied included the UxV properties: numbers; failure rate; endurance and deployment/recovery times. The scheduling policies of deployment and recovery used by the mother ship were also modelled and examined. The next stage would be to develop more detailed models to confirm the insights found by this study but excluding variables that were found not to be important and increasing the fidelity in areas that were found to be more important. From there trials and experiments would be used to validate both this model and the more detailed one. The more detailed model would then be in a position to provide advice to decision makers regard the acquisition of an actual system.

Trials currently being undertaken by DSTO using UxVs have informed the choice of data values for this study, but are not currently developed enough to be examining the scheduling aspects. Indeed, this was a driving consideration in the decision to undergo this study.

Rate of effort was found to depend on the chosen deployment policies. Retrieving and deploying the UxVs as soon as possible after their endurance is exhausted is often the best policy. However, this is not generally optimal behaviour, for instance as failure rates increase. The stochastic nature of failures can lead to delays which disrupt the schedule. These effects may be mitigated though the choice of different policies.

The rate of diminishing returns in terms of total rate of effort as the number of UxV is increased is most closely related to the endurance to deployment time ratio and the deployment policy. As expected, UxVs with long endurance with respect to deployment and recovery times are preferable.

Future work may include further exploration of the deployment policy for the mother ship and the inclusion of multiple types of UxV including semi-autonomous models (which would require a degree of attention from the mother ship). Complementary geospatial modelling to track the location of the UxV whilst surveying could also be included as a stepping stone towards modelling mine counter-measure operations.

Keywords: *Hydrography, unmanned vehicles (UxVs), discrete event simulation, Simulink*

Suppression of Dismounted Soldiers: Towards Improving Dynamic Threat Assessment in Closed Loop Combat Simulations

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Abstract: Closed loop combat simulations are part of a suite of analytical tools used to help inform decision makers about various military options and potential acquisitions. A common limitation of many current combat simulations is that entities often use scripted or time-based behaviours which limit their ability to imitate the dynamic nature of combat. In addition these behaviours cannot typically be used to simulate other military environments or scenarios without resource intensive input from both military subject matter advisers and simulation experts.

In this paper we attempt to address some of these limitations by applying and adapting techniques being used in both the computer gaming industry and the military research community. We propose a conceptual framework for modelling suppression in combat simulations that incorporates dynamic cognitive assessments of known and perceived battlefield threats, perceived cover locations, physiological state and social forces such as morale and leadership. We create a representative implementation of key aspects of the model in an agent-based test environment and apply it to a simple military scenario. We fuse information based on enemy lines of sight, incoming enemy fire, friendly lines of fire and the perception of dangerous areas of the environment to generate an individual "danger map" for each entity. An individual suppression model and social pressures based on simple team rules are incorporated with the danger map to generate dynamic entity behaviours.

We create a baseline behaviour type that is representative of that used in current closed loop simulations and progressively add dynamic behaviours based on the model described above. The results show that the more sophisticated dynamic behaviours increase force survivability while producing battles that are longer and provide a better representation of the ebb and flow of many combat situations.

Keywords: *Suppression, Defence, Military, Simulation, Operations analysis*

A Discrete Event Simulation of the Joint Space Cell

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Abstract: The Australian Defence Force (ADF) has formed a joint space cell (JSC), to develop a set of information products to provide space situational awareness (SSA) for the Australian Defence Organisation. The JSC responds to information requests that can arrive from any agency or group within Defence. The ADF is considering different resource allocation options to enhance the capabilities offered by the JSC. To this end, we are investigating the characteristics of the relationship between the quantity of allocated resources and the rate of output through the following analytical questions:

1. What are the expected waiting times of customers requesting SSA products, given the current production process and operator allocation?
2. How many operators could be efficiently utilised within the JSC, given the existing processes for producing SSA products?
3. Is it possible to achieve significant reductions to customer waiting times through the automation of a subset of SSA production processes?

This paper reports on problem formulation, modelling and simulation approach, data acquisition and interim results. We have taken a queueing systems approach to model the operational mechanics of the JSC. We treat the operation of the JSC as a manufacturing process for information products. The JSC produces a portfolio of products and operates with a single queue and multiple servers. We have used the JSC's email traffic to characterise one of the arrival parameters of the queue. The service time that each customer experiences depends upon the product that is requested.

The results from the email analysis indicate that the exponential distribution may be used to model the daily arrival of emails into the JSC. The simulation output indicates a combination of deterministic and stochastic behaviour which is consistent with the use of the triangular distribution for generating service times.

Preliminary results indicate that DES is a reasonable approach for modelling the JSC and will provide a capability to aid decision making.

Keywords: *Discrete event simulation (DES), queueing, email analysis*

Supply chain contract parameter optimisation to manage surge in demand for military operations

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Abstract: Procurement is a vital part of any military operation planning process. One approach to ensure sustainability of military operations with little or no warning time (e.g. disaster response) is to maintain sufficient reserve stocks, which act as a buffer to meet lumpy unforeseen demands during the period of operation. However, this does not always lead to a preferable solution because of issues related to storage and upkeep of such a reserve. A better solution for sustainability is to negotiate supply chain contract parameters, such as lead time and maximum order quantity with suppliers for faster delivery of more stock to meet the surge in demand.

This paper presents a two dimensional binary search heuristic based algorithm to solve the supply chain contract optimisation problem. The problem is to find optimal values for the supply chain contract parameters of a supply item so that total amount of reserve stock required for that item to sustain the military operation is zero or very low (i.e. under a user specified threshold). We first transform the problem into a decision problem by creating a search space, and then utilize the binary search heuristic to find an optimal value from the search space.

Since the proposed heuristic is based on binary search, the worst case complexity is logarithmic making it computationally efficient compared to other heuristics or meta-heuristics based optimisation techniques, especially when lead time or maximum order quantity variations are large, i.e. the search space is large. We conduct simulation to demonstrate the effectiveness of our proposed optimisation technique, and present the simulation results for different variations of the surge in demand.

Keywords: *Optimisation, surge, supply chain contract, lead time, maximum order quantity, binary search*

Integrated Submarine Performance Simulation

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Abstract: The procurement planning for high value assets, such as submarines, naval surface ships, aircraft, etc. requires rigorous analysis to ensure that the operation of the platform and its sub-systems meet the capability requirements, based on measures of performance. Measures of performance are identified and defined in a capability analysis, which is not in the scope of the present study. Once the measures of performance have been established, a submarine simulation model can be used to assess the performance of a given design against the measures of performance.

Subject matter experts are able to develop high fidelity models of submarine performance and operations. An efficient way to integrate these high fidelity models, to develop a whole-of-submarine simulation model, is to use an integration tool such as Phoenix Integration Model Center. This integrated tool can be used to perform analysis and parameter sensitivity studies to provide a better understanding of the design space.

In this paper, a submarine simulation model is developed, using Phoenix Integration Model Center, based on sub-system models developed by subject matter experts. The software tool is validated by comparing the designs to several previous designs described in the public literature.

The tool is then applied to a case study, showing the relationship between the weight of a submarine, the number of crew members and the length of its mission in days. The results show a large growth in submarine weight with increasing crew numbers, and a moderate growth in weight with increased mission duration.

Keywords: *Submarine, Simulation*

Microsimulation Study of the Release of Pneumonic Plague and Smallpox on a Synthetic Civilian Population

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Abstract:

The confrontation in Syria during 2013 is an ongoing cause for concern regarding the potential use of chemical and biological weapons. There have been reports of the use of chemical weapons including Sarin (BBC, 2013a) which UN chemical weapons inspectors are investigating (BBC, 2013b). If chemical weapons have been used by either side, then the potential use of biological weapons cannot be disregarded. In addition to stockpiles of chemical weapon (BBC 2013c), Syria is thought to have stockpiles of a number of biological agents including anthrax, plague, tularaemia, botulinium, smallpox and cholera (Gordon, 2007). Some groups sympathetic to Al Qaeda might also have access to some of these through their terrorist networks. Because these weapons can have a substantial impact beyond the immediate conflict zone, there are serious questions about how best to respond efficiently to their use and manage their impacts.

One such concern is whether the response to an attack involving a single agent would be the same as when more than one agent is used. There are indications that infectious diseases which promote cytokine response can have a protecting effect on infection with a second disease (Graham et al., 2007, Barton et al, 2007). Plague affects the innate immune system by suppressing cytokine responses (Li et al., 2008) while smallpox activates the cytokine response (Fenner et al, 1988). Such an interaction is therefore possible with smallpox and plague in people who are infected with both diseases. While there are a number of papers on the management of both smallpox and plague (Halloran, (2002), Rani et al, (2004)), there are few, if any, which discuss infection by both agents simultaneously or the likely confounding factors that will affect outcomes in their infection control after the attack. In this paper we explore the application of microsimulation modelling of a simultaneous attack on a civilian population using plague and smallpox as an example of a simultaneous coinfection through its effect on the spread of disease and number of deaths

As a basis for analysis, we have developed simulations involving a population of 1250 people based on NSW statistics for households and work. The structure of a community model of social mixing is briefly discussed, over which a multi-infection model is imposed that accounts for varying infectivity in different stages of each disease as well as confinement to home as each disease progresses. A number of simulations were run assuming 10% immunity to both diseases, to establish a baseline for each disease in the community. Further simulations were used to model the delay of the introduction of plague compared to smallpox between 0 and 35 days respectively. The strength of the immunological interaction by smallpox on plague deaths was also investigated. Each scenario was repeated 10 times to assess the variability.

Our model showed the outcome is complex as the number of deaths is dependent on the delay in the release of plague and varies according to the number of people progressing through the active release locations that can infect them. Additionally confinement to their household during the later stages of both diseases reduces the number of susceptible people in the general community although it still allows for spread to other household members. It was found that the number of confections was about 10% of the total number infected and that the reduction in deaths from plague where the two infections were present also depended on how many smallpox cases were at the correct stage of development compared to the plague infection. We believe that the use of microsimulation has a benefit in that many of the human factors that affect delay in control and hence the size of any epidemic can be easily incorporated into the simulation without affecting the other components of the simulation. For example, vaccine and drug supply can be added as additional peeps that move to hospitals or doctors' surgeries and then interact with the human population through creation of additional states based on these locations. Further work is planned to assess the impact of these human factors on preventing epidemic spread as well as assessing current WHO guidelines for each disease. The intention is to develop protocols for application both within and outside of conflict areas. Progress on this will be reported at the conference.

Keywords: *Bioterrorism, Microsimulation, Plague, Smallpox, Disease Management*

Statistics of chemical tracer concentration in a multi-compartment structure measured with a sensor network

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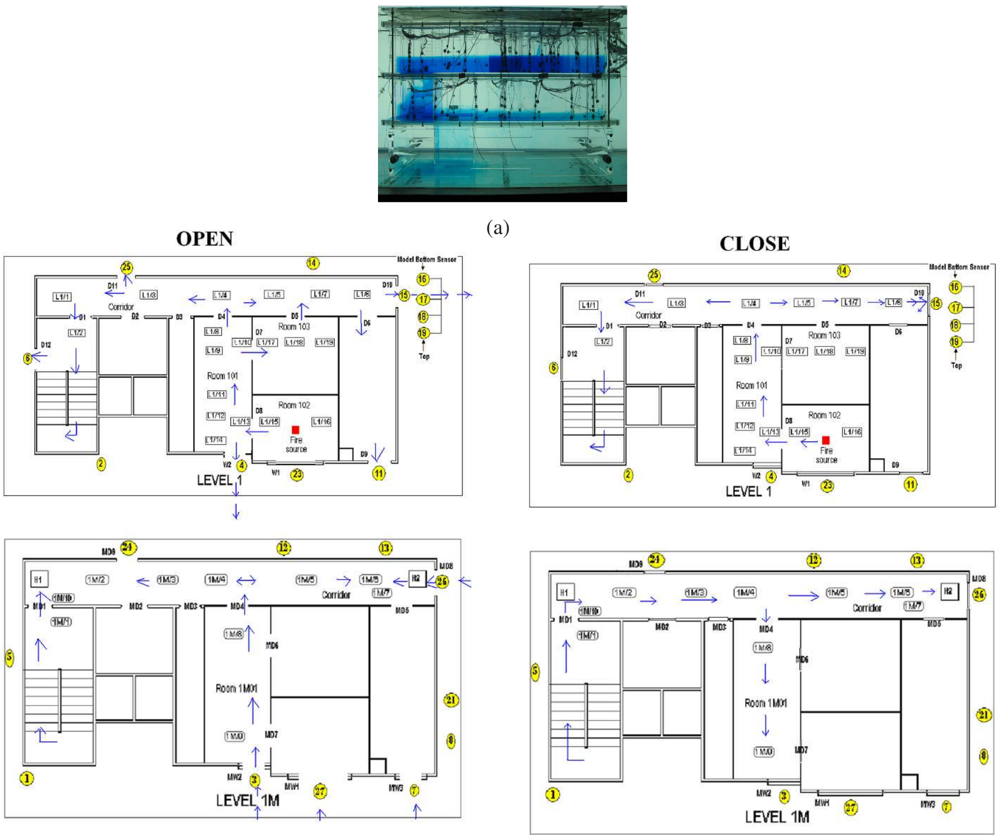
Abstract: An understanding of the statistics of concentrations of chemical tracers dispersing through multi-compartment structures such as buildings, ships, and aircraft is important in many applications (e.g., industrial, military, and ecological). Such an understanding can be useful for early detection of hazardous releases, source backtracking, and assessment of their impact on engineered structures (e.g., buildings, aircraft, ships). It may be also important for design of monitoring sensor systems. We present the statistics of chemical tracer concentrations obtained by analysing recent experimental data obtained in a study of tracer dispersion in a complex structure. The experiment involved the release of a tracer (dyed salt solution) from a point source placed inside a multi-compartment structure (Fig. 1) embedded in a water tank and measuring the salt concentration at different locations within the compartments using a network of conductivity sensors. We show that moments of measured concentration at a given sensor depend on the Euclidean distance between the source and the sensor, resembling the behaviour observed in advection-diffusion transport in porous media.



(b) (c)

Figure 1. The experimental setup: (a) Image of the multi-compartment structure used for the experiment; (b) the flow path in the OPEN configuration; and, (c) the flow path in the CLOSE configuration.

Keywords: chemical tracer, concentration, statistics, multi-compartment

An Investigation of the Effectiveness of Interdiction Regimes Against Terrorist Attacks in an Urban Transport Hub

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Abstract: This paper examines the effect of varying attack and interdiction strategies, both alone and in combination, in an urban transport hub. Particular attention is paid to the potential disruption to normal commuter services resulting from an intrusive stop and search regime.

The work presented here represents a qualitative investigation in that many parameters relating to the details of the interdiction mechanisms are first-order approximations. However, the background against which the investigation is conducted has been constructed to be as realistic as possible.

The simulation is performed using our generalised microsimulation framework *Simulacron*, along with a repertoire of simulation modules. Changes and additions to these modules required for the present study are described.

The station is modelled using 454 distinct locations, most of which are interconnected to form a directed graph to permit commuter movement. An average of some 8,300 commuters move through the station, outbound and inbound. Figure 1 is a frame from the baseline simulation of the station, generated by a custom post-processing tool and rendered by LightWave, showing commuters and trains. The train schedule is constructed from the real schedule for the 3rd of June, 2013. It is from this that the commuter population is derived.

Five attack strategies (including no attack) are matrixed against four interdiction strategies (including no protection) to produce 20 scenarios. Some key results are presented, along with brief remarks on the remainder. An additional 30 variant scenarios were used to examine a stop and search interdiction strategy. For these scenarios, impact on commuters was inferred from the number of outbound commuters missing their intended train, how long commuters spent waiting in checkpoint queues, and the size of these queues, on average and at peak. Congestion at the search point was also used as an indication of the increased vulnerability resulting from stop and search.

Our conclusions from this work are that overt, intrusive protection schemes appear to be more efficacious than passive or covert means. However, the former present their own problems in both disruption to commuter activities and the creation of new potential targets. In the case of stop and search, this takes the form of unacceptable commuter delays and congestion at the checkpoints. As a result of this, the overall interdiction regime must be adjusted to protect the new target. Doing so without introducing additional targets may prove challenging. It seems that the "best" likely outcome is to redirect the terrorist attack to a softer target.

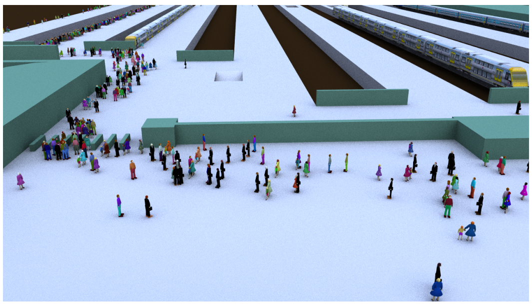

Figure 1. Visualisation of the baseline simulation.

Keywords: Simulation, terrorism, attack, interdiction.

Algebraic models for path-based measures in time-ordered social networks

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Abstract: The analysis of the structure and dynamics of networks is now recognised as a significant and valuable enterprise in many distinct fields, including the biological, social and physical sciences. Our particular interest is in the analysis of social relations and interactions that are only current over finite time intervals. Since such interactions are played out sequentially, the order in which they occur is important (e.g. turn-taking in conversations). In particular, time order has implications for the diffusion of resources, attitudes, diseases, etc., through various kinds of networks, and imposes a time-respecting constraint on network paths. Ignoring the sequence of relational events results in a potential overestimate of path-based measures, such as reachability, and hence impacts all other associated measures. In this paper we consider a class of network path problems, in which paths are formulated in terms of weighted edges between two nodes. The edge weights are given by the interval or set of intervals over which interactions occur. Reachability in this context gives us an indication of potential flow between two nodes along any path for which the aggregate weight of the path is a non-empty set of time intervals. For measures that depend on geodesic distance between the specified pair of nodes, we determine an appropriate definition of the length of a path in our set of problems. In a network with time-ordered edges we may either define shortest paths to be the ones with the least number of interconnecting nodes; or the ones that deliver the earliest possible transmission: our algebra can accommodate both.

Despite the applied nature of social network analysis, it is often valuable to regard networks as abstract algebraic structures and hence take advantage of the fact that mathematical representations facilitate the potential application of analyses developed and understood in one domain of application to another. The algebra for static networks is based on the Boolean addition and multiplication operations over the set $\{0, 1\}$ of possible edge values or weights.Thus, constructing network paths entails composing or multiplying edge weights to determine node adjacency. We present analogues of these operations and associated algebras for sets of temporal intervals over which interactions are observed. These operations allow us to construct time-ordered network paths in which consideration is given not only to node adjacency, which is the only consideration in static network path construction, but also to the sequence of relational events. In particular, we define operations which compose two or more interval sets and whose result is the path interval set over which flow might be possible. The actual form of the composition is determined by the nature of network flow, so for example in the case of a particular disease transmission, if we let $E_{ij} = [u, v]$ be the time interval over which node i is in contact with node j and $E_{jk} = [t, w]$ be the time interval over which node j is in contact with node k, we might define a basic composition operation $\otimes$ as:

$$E_{ij} \otimes E_{jk} = \begin{cases} [\max(u,t), w] & \text{if } \max(u,t) \leq w, v \geq u \text{ and } t \geq w, \\ [\,] & \text{otherwise.} \end{cases}$$

So $E_{ij} \otimes E_{jk}$ represents the interval over which the time-ordered path from i to k through j exists and transmission is possible. This interval is non-empty either when the two relational events are concurrent (i.e. one interval overlaps another) or when one precedes the other. In these cases, the interval starts at the later of the two interval onsets ($\max(u, t)$) and ends at the offset of the second interval, w.

We introduce very general path construction operations for dynamic relations and explore their utility in determining sequential patterns in relational data, including time-ordered triads and time-disjoint paths. Our approach reflects the need for a variety of different approaches to representing and analysing flows and potential flows in social networks. A very topical application of dynamic relational analysis stems from a consideration of the Internet as a locus of social processes and the spread of ideas and attitudes.

Keywords: Social network analysis, time-ordered paths, network path problems, algebraic network models.

Using models to compare the effectiveness of alternative complex security arrangements

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Abstract: Evaluating the effectiveness of complex (national) security systems and arrangements such as national infrastructure or large military or infrastructure facilities has proven to be a difficult problem. In the absence of a framework to manage the uncertainty and complexity, security agencies have found it difficult to take an objective stance on priorities for system enhancement and the allocation of limited resources. Developed over the past few years, and honed by application to real-world security problems, we present a framework for the design and evaluation of security systems that provides a traceable and defensible means to prioritise development and allocate resources. It is based on a 'security-in-depth' framework that we developed to separate security into sequential and logical layers.

The security-in-depth (or SiD) framework identifies *security layers* as high-level integrations of *security controls* (such as guards, cameras, barbed wire, alarm systems etc.) performing coordinated *security functions* (detection, alert, response, neutralisation etc.) in a way that either stops a harmful event from occurring, or potentially eliminates its harmful consequences. Only security *layers* can reduce security risk. The model indicates that national security relies on seven layers, each of which has a different role in treating strategic security risk. They are: *shaping*, *deterrence*, *prevention*, *protection* and *containment,* each of which manages the risk of an unfolding harmful event. *Resilience* manages the escalation of immediate or local consequences up to national significance, and *investigation* (which includes the function 'prosecution') reduces the risk of future events.

The layering model breaks the complex security situation into sequential, simpler, and more tractable parts, and allows exploration of the trade-offs between alternative system enhancement proposals, or 'security strategies'. Against any single threat and its pathway, it is possible to identify the layer(s) that contribute(s) most to risk reduction. The SiD construct argues that security effectiveness is then best enhanced by investing in the weakest functions within those layers. In attempting to manage a spectrum of threats when each can follow several pathways, the problem of resolving an appropriate balance of investment across the layers quickly rises beyond the analytical/cognitive capabilities of experts. Understanding the trade-offs required is then a quantitative (modelling) problem.

Rather than asking experts to assimilate all of the complexities by asking them to compare 'security strategies' at the whole-of-system level, we ask them to characterise their expectations of the way that a single layer would be improved against a particular threat/pathway. Their subjective opinions are captured by probability distributions of the layer's performance. Monte Carlo simulation (essentially, of their opinions), combined with the model of the layers, can then be used to simulate the aggregate opinion about the value of a security strategy, When the output distributions are carefully compared using statistical techniques, such modelling enables quantitative comparison of complex alternatives and, potentially, an argument for robust optimal strategies that is more traceable and defensible than simply capturing expert opinions on the complex system as a whole (or trying to aggregate judgments about the performance of single controls, when those controls are strongly inter-dependent).

The veracity of modelling depends upon the correct identification of security layers, the comprehensiveness of threat and pathway analysis, and the quality of the method of capturing expert opinions.

The presentation will outline what we have achieved so far, and its meaning for security investment decision-making. We will provide an example from a security management problem for a defined facility, and outline the method's potential extension to strategic security problems.

Keywords: *Security-in-depth, Monte Carlo simulation, security evaluation, decision-support.*

Modeling and Simulation for Homeland Security

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Abstract: Critical infrastructure and its interdependencies play a vital role in our daily functions. Our economies, government, and way of life depend on the sound function of these integrated systems. Analysis of these systems, however, has historically been limited: system owners and operators have limited information outside their domain space (and that legal impediments often limit their ability to better understand the broader system), and very few entities have the desire to better understand these systems as a whole, let alone their interconnections. The National Infrastructure Simulation and Analysis Center (NISAC) is one such entity.

NISAC, a program managed by the U.S. Department of Homeland Security (DHS) and comprised of a core partnership of Sandia National Laboratories (SNL) and Los Alamos National Laboratory (LANL), draws on years of modeling experience of various types, focused on infrastructure, population, and the economy, to examine questions pertinent to DHS regarding the function of economy and critical infrastructure of the United States (see Figure 1).

This paper is designed to provide a background on the NISAC program as a whole, including a description of the legislative and funding history behind the program. Additionally, a review of the program's early days, and the modeling and simulation tools developed for other customers that were repurposes and enhanced to meet homeland security mission space is performed. The beginnings of rapid response analysis are discussed; these grew in significance as the result of events such as Hurricane *Katrina*, and brought about changes both to processes and tool development. These events also led to a change in NISAC's analytic thought process, from an exclusively reactive one to an increasingly proactive one; this change in thought has led to the development of capabilities to address as-yet unseen events that provide US DHS both with benchmark analyses that can be used in the events of a similar event, as well as capabilities to address similar real-world problems. A review of the path ahead for NISAC highlights both the challenges and potential for the program as it moves into its second decade.

Figure 1. NISAC uses a range of modeling capabilities across the set of critical infrastructure sectors to address questions of consequence to infrastructure, populations, and the economy for hurricanes, earthquakes, pandemics, and other changes to the normal function of systems.

Keywords: *critical infrastructure, modeling, analysis, National Infrastructure Simulation and Analysis Center, NISAC*

Development of a Life-cycle Sustainment Conceptual Model for a Virtual Fleet Environment

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Abstract: Many of the Australian Defence Organisation's (ADO's) new Air assets acquired over the past decade will be sustained through a Foreign Military Sales (FMS) agreement, where Australian assets form part of a larger global fleet, comprising mainly of those in the United States Department of Defense (US DoD). This 'virtual fleet' (VF) construct is designed for smaller nations, such as Australia, to benefit from the economies of scale and performance-based agreements between the prime contractor and the US DoD.

This new paradigm is used in sustaining the ADO's six C-17A Globemaster heavy air lift aircraft; first introduced into service in 2006. The majority of sustainment support is delivered by the Globemaster Integrated Sustainment Program (GISP); a US Air Force (USAF) managed Performance-Based Logistics (PBL) contract between the USAF and Boeing (US). The GISP provides the mechanism by which the ADO, and other 'VF partners', are able to leverage their fleet support off the USAF program. Whilst there are substantial advantages to the 'VF partners', this sustainment arrangement creates a system that is heavily outsourced and complex, thus creating new socio-technical challenges for the fleet manager.

The Defence Science and Technology Organisation (DSTO) has developed a life-cycle sustainment conceptual model tailored to the C-17A VF construct, which includes an asset management framework based on the 'British Standards Institution' specification BSI PAS55:2008. The advantage of the framework is that it integrates key asset management principles, such as strategic planning, asset knowledge, decision making, risk management and organisational planning. The conceptual model is designed by combining the asset management framework with an understanding of the key linkages and limitations between major stakeholders in the C-17A VF construct.

During the development of the model it was identified that leadership, competency and agility were the three key enablers required by the ADO to identify C-17A Australian unique risks at different stages of the life-cycle - the management of these risks are essential for the effective and efficient sustainment of the C-17A fleet up to the Planned Withdrawal Date. The techniques used in identifying these enablers involved data mining of fleet readiness and cost data; systems engineering, system support mapping; services management and information systems analyses; and subject matter expert judgement.

The leadership aspect particularly focussed on the ability to align sustainment strategies to goals within the VF construct in addition to country-unique requirements. The competency aspect considered the ability to adequately provide value and demonstrate due diligence in a heavily outsourced virtual environment. The agility aspect focused on the ADO's ability to respond, exploit and adapt to changes to the C-17A sustainment environment, several of which are out of the control of the ADO.

A key finding from the initial implementation of the model was that a 'Master Sustainment Plan' (MSP) was required to capture the key attributes of the three enablers, all of which are interrelated and vary at different stages of the life-cycle. Additionally, periodic 'fleet sustainment assessments' should be conducted to assess the effectiveness of the plan, and more importantly, ensure all sustainment risks, especially those Australian unique, are managed appropriately.

A key advantage of the life-cycle sustainment model is that it is conceptual by nature and hence the key attributes are directly transferrable to other platforms managed under a VF construct. The model has sparked interest from Australian Super Hornet, F/A-18F, fleet managers. The model also reveals some of the context, inputs and constraints/processes involved in modelling future fleet optimisation and scheduling problems in the ADO under a VF construct.

Keywords: *Virtual Fleet, asset management, fleet management and sustainment*

Using discrete-event simulation to predict the size of a fleet of naval combat helicopters

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Abstract: This paper describes the methodology developed to determine the size of a new fleet of combat helicopters for the Royal Australian Navy. The Australian Government's 2009 Defence White Paper described "as a matter of urgency" a requirement for a fleet of helicopters "to provide eight or more aircraft concurrently embarked on ships at sea". The objective therefore is to find the minimum fleet size that enables the fleet to meet both this minimum daily embarked requirement, as well as annual requirements for a specified number of flying hours for both embarked helicopters and the remaining ashore-based fleet.

The fleet sizing problem incorporates the helicopter fleet, ships, personnel and a home base with maintenance facilities. Individual helicopters (or *tails*) pass through various states throughout their life. These include the serviceable state when they are able to fly, or a range of maintenance states which will make them unable to fly. Maintenance types include regular inspections, phased maintenance and deep maintenance. Many of these states can occur when a tail is either embarked or ashore. Unscheduled maintenance adds a random element to the problem and influences which aircraft may be serviceable on a day-to-day basis. A discrete-event simulation approach was chosen to address this problem, due to the requirements to track tails in various states, test for state transitions and incorporate random effects.

The fleet sizing model begins using the nominated fleet size as an input, along with the required number of embarked aircraft and the annual embarked and ashore flying hours. Other inputs include maintenance data regarding the time between services and their duration. The fleet is initialized with the required number of tails embarked and the remaining ashore tails in various serviceability and maintenance states.

The model runs for the expected fleet life of 30 years, stepping through one day at a time. At the beginning of each day, it is determined whether it is a work day for ashore flying crews or maintenance crews. Embarked crews work every day of the year. Embarked serviceable aircraft will fly a certain number of hours depending on their operational tempo. A procedure is used to balance the flying hours of the embarked fleet while accounting for their expected and realised maintenance, in order to meet the annual requirement.

If it is an ashore work day, the next step is to allocate flying hours to aircraft, and maintenance crews to maintenance lines. As a baseline, a flying allocation method is used that seeks to minimise queuing of aircraft for phased maintenance. This is compared with a greedy technique that seeks to meet the daily requirement first, but at the expense of lower serviceability. Similar methods are used to allocate maintenance resources. The baseline in this case is allocating the same number of personnel to each maintenance line for both flight line maintenance (which handles regular inspections and unscheduled maintenance) and phased maintenance. An alternative is a greedy technique applied to flight line maintenance, where personnel are pooled and the aircraft with the least number of maintenance manhours is serviced first. This will increase the serviceability of the fleet, but may leave aircraft requiring a large amount of maintenance unserviceable for a long time.

Once the allocation of resources is completed, aircraft will fly or be maintained accordingly. At the end of the day, tests for state transitions occur. Aircraft will move in and out of scheduled or unscheduled maintenance, or in and out of a serviceable state, subject to criteria being met. Disembarking aircraft need to be replaced immediately. The model can also include tails going on exercises or being lost from the fleet.

To demonstrate the capability of the model in sensitivity and trade-off analysis, results are shown for a generic helicopter against an indicative requirement. The greedy maintenance allocation heuristic is shown to be superior, even superseding the differences between the flying allocation methods. When a modification program is included, a large decrease in ashore hours occurs due to queuing for deep maintenance during the mid-life upgrade, which can be overcome by increasing maintenance capacity. These results clearly show the influence that resource allocation and maintenance capacity can have when predicting fleet size.

Keywords: *Discrete-event simulation, military application, fleet size, resource allocation, heuristics*

Assessing Ship-Based Helicopter Fleet Sizes using a Discrete Event Simulation

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Abstract: The Royal New Zealand Navy (RNZN) has a number of vessels equipped with helipads and a fleet of Seasprite helicopters which can be utilized for various deployments. Given the possibility of future upgrades to this fleet, we have developed a discrete event simulation to assess the effectiveness of different fleet sizes. Our model uses the concept of a central pool (see Figure 1) from which helicopters can be drawn each day for deployment or training activities. However, helicopters might also be removed due to scheduled maintenance, deep maintenance or unscheduled repairs. Effective management of the fleet requires maintaining sufficient helicopters in the pool so that all training requirements can be met and helicopters are available for any departing vessels.

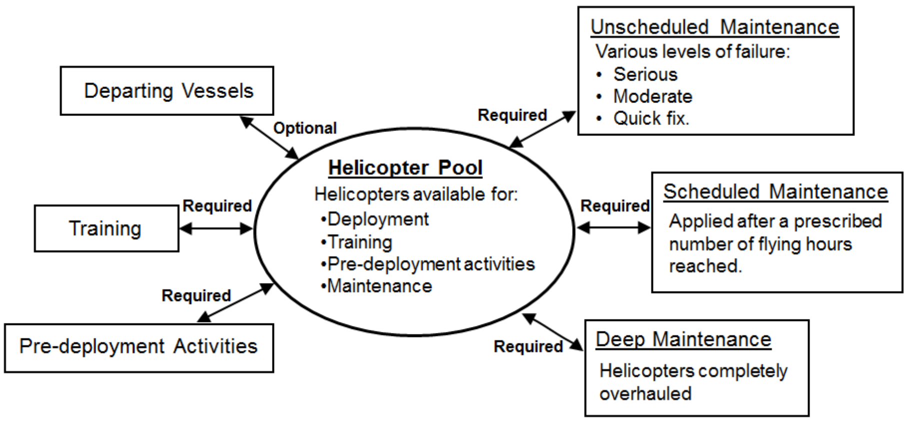

Figure 1. Schematic representation of the helicopter fleet size model. Helicopters go into scheduled or deep maintenance based on flight hours accumulated and pre-defined schedules. Probabilities for failures leading to unscheduled maintenance are obtained from an exponential distribution.

Our model is run over the lifetime of the fleet with tests carried out each day to determine the state of all helicopters: for example, whether to deploy, suffer a particular category of failure, go into scheduled maintenance or be returned from repair. Running the model multiple times allows average quantities to be obtained such as the likelihood that helicopters will be available for deployment. Figure 2 gives an example for a fictional navy with 8 vessels having helipads. This shows the likelihood that a particular vessel will be unable to acquire a helicopter for different fleet sizes.

Despite the simple nature of our model, the interaction between all entities leads to a rich variety of behaviour and accompanying insights. We can investigate different fleet sizes and the importance of factors such as vessel deployment schedules or the time taken for repairs. We can also explore methods for managing the helicopter fleet more efficiently; whereby the differences between average and worst case results in Figure 2 are reduced.

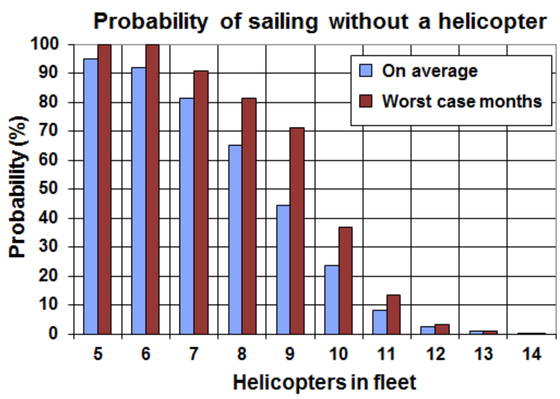

Figure 2. Probability of at least one vessel sailing without a helicopter for 8 vessels with helipads.

Keywords: *helicopters, fleet size model, discrete event simulation, sensitivity analysis*

Army Vehicle Fleet Size Analysis: Modelling Tool and Analytical Approach

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Abstract: This paper presents a case study of the application of a purpose-built software tool to analyse fleet sizes for future Australian Army vehicles. The modelling tool was developed as a deterministic, discrete-time, dynamic model. It assesses a force structure's ability to meet specified vehicle numbers for readiness and operational requirements over a multi-year timeframe. Each vehicle type is modelled independently in monthly time steps. The model design is based on two modules; a demand module and a supply module.

The demand module contains a representation of the make-up of the force structure including the directed number of vehicles required at different stages and the scenario to be investigated, which links parts of the force structure to readiness requirements and planned operations. At the start of each time step, the demand module aggregates the demand for each vehicle type and provides population targets to the supply module.

The supply module is based on the concept that the number of vehicles available is affected by two types of maintenance – scheduled overhaul and non-scheduled – as well as procurement and loss (e.g. battle damage). The available population of each vehicle type for each operational or readiness level is defined by a distribution across an array. Scheduled overhaul maintenance is modelled as a cycle between vehicles being available or unavailable, and it is the time between overhauls that defines the size of these arrays; i.e. the number of elements in the array is equal to the number of months between overhauls. During the model run vehicle populations are moved up one element in the array (i.e. one month closer to overhaul), apart from the last element which is moved into the overhaul maintenance array. A capacity constraint can be placed on overhaul maintenance and any excess vehicles are added to a queue class. Unscheduled maintenance is modelled by simply applying a temporary loss rate for a single month at every time step evenly across the vehicle array and is not capacity constrained; i.e. a percentage of vehicles are assumed to be unavailable at any time unexpectedly. Losses are applied as a percentage evenly across the array of available vehicles; for deployed units, battle damage is modelled as a discrete distribution defined by a percentage and the delay before damaged vehicles return to service. Most input parameters can be set by operation or readiness level. Movements of vehicles between levels are managed via a priority sequence, with operations receiving highest priority. Commensurate with current policy, vehicles remain in theatre and do not rotate with units at the end of a tour. Vehicles enter quarantine only at the expiration of an operation for a user-defined period.

Two studies have been completed using this modelling tool. The first study investigated an operational scenario with three policy options for collective training support (in terms of both the duration and number of vehicles required). Each run of the model was iterated multiple times, amending the initial pool stock levels until there were sufficient vehicles to fully sustain the target populations for the duration of the scenario, assuming a single production run. A simple parametric analysis was conducted across three cases (best, baseline and worst) for each of the three options and five key input parameters (overhaul period, frequency of overhaul, availability rates, loss rates and return to service rates). Results were provided on the number of vehicles required to sustain each of the cases; results were further broken down by operations, training, support activities, maintenance pools and vehicle fatalities. The results were used to validate SME judgments on Basis of Provisioning sizes. A second study for a separate project was conducted similarly but considered the required fleet sizes across 13 different vehicle classes to support a proposed concept of employment.

The unique contribution of this work includes: (i) the flexibility to quickly analyse a range of deployment options, including concurrent operations; (ii) the ability to investigate a range of force generation policies and set parameters appropriate for each part of the cycle; and (iii) functionality allowing representations of force structures/scenarios to be quickly created/amended. The approach described here has broader application in both the military (e.g. to other capability inputs, such as personnel, facilities and supplies) and non-military environments (e.g. to model fleet sizes for large companies investing across numerous sites, such as in the mining or aviation sectors).

Keywords: *Fleet size analysis, Modelling tool, Army vehicle application*

Force Generation Plan Automation for the Royal Australian Navy

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Abstract: The Royal Australian Navy's (RAN) Force Generation Plan (FGP) details the day-to-day operations of about 120 ships, crews, submarines, diving teams and air assets plus miscellaneous entities. The FGP is an annual directive concerned with scheduling the activities that are undertaken by the RAN units. Required activities are specified in an associated document called the Navy Activity Schedule (NAS). The NAS provides overarching guidance to RAN maritime operations planning staff on Navy’s priorities and resource levels for operational commitments, preparedness levels and international and domestic engagement activities.

The FGP is manually generated as a result of interactions and conferences involving Navy operations’ authorities. A scheduling tool, the Fleet Activity Management Tool (FAMT), allows schedulers to coordinate unit assignments to activities while keeping track of other factors such as requirements for units to undergo maintenance and personnel to have rest and recreation. The scheduler makes heuristic choices based on ‘business’ rules dictated by policy documents. However, while FAMT can help to generate the FGP, the actual scheduling of units to NAS activities requires an operator to make the assignment. Manual scheduling can be time consuming and is not guaranteed to cover all the required activities in the most efficient manner. Typically, much iteration of the schedules occurs.

This paper describes a simple decision support system for scheduling RAN fleet units using automation. The paper starts by describing the employment allocation problem and the constraints conditioning the generation of an appropriate overall schedule. Then it focuses on describing the heuristic approach of the solver using a simulated annealing algorithm, together with its flexible interaction with the planning tool FAMT.

The optimisation model developed here offers schedulers the advantage of considering many candidate schedules to determine the best schedule. Apart from the obvious opportunities for labour reduction, automation also offers the advantage of providing a consistent repeatable process with robust evaluation criteria as to the quality of a FGP. In comparison to an actual FGP, the FGP generator demonstrated an improvement in the allocation of units to the NAS by about 30% on key fleet management measures, with commensurate improvements to training opportunities and preparedness. Trial runs of the FGP generator consistently found satisfactory unit allocation schedules for difficult pathological scenarios.

This research shows that automation of the FGP can lead to substantial improvements in efficiency, while maintaining satisfactory unit programmes, and ensuring that RAN fleet units can meet their on-going and emerging commitments. The solver has been integrated into FAMT and is available to schedulers. The paper notes some avenues for improvement of both FAMT and the FGP solver and the method’s applicability to wider defence resource allocation problems.

Keywords: *Scheduling, Optimisation, Heuristics, Simulated annealing, Naval units*

EXTENDED ABSTRACT ONLY

Utilising empirical data to identify risk and prioritise treatment

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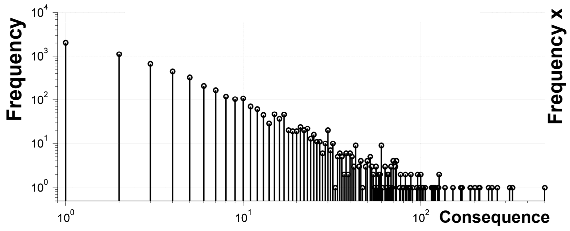
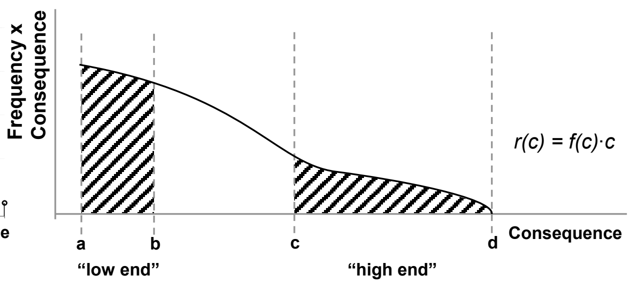
Abstract: National governments are increasingly using risk language when describing and assessing strategic issues such as natural hazards and anthropogenic threats. This approach supports comparison of multiple threats and prioritisation of treatment solutions.

It is common to see national threat assessments represented on a likelihood-consequence risk matrix where each point on the graph represents the likelihood and consequence per threat, over a selected time period. However, most threats of strategic relevance such as earthquakes, pandemics and terrorism follow a distribution in size of events. As an example, there are many small earthquakes over a given time period causing limited structural damage and a small number of casualties per event, but there are a small number of very large earthquakes resulting in immense structural damage and a large number of casualties. Representing the risk of such threats as a single frequency-consequence pair is inadequate for several reasons. Firstly, should the single point represent the average observed consequence, or should it be represented as the most likely scenario or a plausible worst case scenario? An additional problem is that reducing a distribution into a single frequency-consequence pair potentially excludes a significant portion of data and their contribution to total risk. Estimating the distribution of event sizes and their frequencies from the available data, and hence estimating an underlying law for the distribution (if there is one), is a better approach for understanding the relative contributions to total risk from high and low consequence events. This may be important when allocating resources effectively to reduce risk, i.e. do the many small earthquakes result in greater numbers of lives lost than a very small number of large earthquakes? Different strategic threats, whether man-made or natural, will likely have different distributions; a common observation though is the fat-tailed power-law distribution.

The process of using empirical data to usefully estimate a distribution in consequence is not a trivial task. The main difficulties arise as a result of finite data sets which reveal sparse extended tails for the high consequence, low frequency events, many of which have only occurred once. This is evident in the left figure for 6034 worldwide 'bombing' terrorist events (1968-2009). This presentation will describe a process and a statistical test used for estimating a power-law distribution from empirical data. Once a distribution is estimated it can be partitioned into regions of low, medium and high consequence events (or regions based on potential treatment options) where the area under the graph between each partition represents the relative contribution to total risk; refer to right figure. This information can be used to inform the risk of strategic threats and support decision makers to prioritise treatment options according to their relative contributions to total risk. The partitions are based on the decision makers' views. The partition points do not have to be sharp; fuzzy set or robust analysis techniques can be used to determine the sensitivity of prioritisation conclusions to the partitioning. This approach is not limited to strategic threats but can be employed at operational or tactical levels to better understand a threat and assist decision making processes.





Keywords: *Risk, frequency-consequence distribution, strategic decision making, resource prioritisation*

A Framework for Determining the Validation of Analytical Campaigns in Defence Experimentation

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Abstract: The problem of looking at modernisation for the Australian Army is that it is wicked in its nature. These problems are generally insoluble and the purpose of analysing them is to better understand them and allow more informed decisions to be made. The recognition of this requires an Analytical Campaign approach to these problems. In these campaigns a balance is sought between three aspects of analytical validity, within resource constraints.

The first two aspects of analytical validity are the conflicting aspects of Internal and External Validity. These are addressed through an iterative campaign that moves across the spectrum applying methods at different levels of each to try and understand the impact. Within Army modernisation methods with high External Validity are used to identify potential areas that will impact Army modernisation. These are then transitioned to methods with high Internal Validity to try and understand cause and effect within these areas before returning to high External Validity methods to validate and contextualise the results.

The third paradigm is that of Philosophical Validity. Generally Army modernisation problems have many ways they can be viewed and have multiple competing stakeholders it is important to try and capture all relevant perspectives to the problem. Within the Army modernisation program Philosphical validity is viewed in terms of the five types of triangulation; Data, Investigator, Theory, Method and Environment.

The aim of this paper is to provide a framework for viewing the overall analytical validity of Analytical Campaigns. The paper then uses two examples to show the balancing of Internal and External Validity and provide a newly introduced framework for understanding Philosophical Validity.

Keywords: *Defence experimentation, analytic validity, multi-disciplinary, trans-disciplinary*

Organisational storytelling with cognitive work analysis: Case study of air power doctrine and strategy narrative

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Abstract: In this paper, a novel application of cognitive work analysis is proposed, specifically that of organisational storytelling. Although cognitive work analysis (Rasmussen, Pejtersen, and Goodstein, 1994; Vicente, 1999) is a reasonably mature framework, having demonstrated its efficacy in relation to a range of systems and applications, its relevance to organisational storytelling has not been investigated before.

Organisational storytelling is a strategy for capturing and sharing ideas in a style that makes the ideas more accessible and memorable than conventional communication strategies (Denning, 2005). Stories provide a means for expressing organisational experience, transmitting values, co-creating vision and strategy, and implementing plans and decisions. Current approaches to storytelling rely on the use of powerful examples for effective communication but, despite their potency, examples are insufficient for complex narratives such as that relating to military doctrine and strategy. For such narratives, cognitive work analysis provides a complementary solution.

Cognitive work analysis is a framework for modelling the work demands of complex sociotechnical systems. Its various dimensions provide a strong theoretical lens for examining the distinctions between such concepts as a system's purposes, goals, values, principles, functions, missions, roles, and characteristics, thereby promoting the development of organisational narratives that are logical, rigorous, and coherent. Moreover, work domain analysis, the first dimension, provides a comprehensive characterisation of a system's purposes, values and priorities, functions, and physical resources. As these properties are relevant across many different actors and situations, a work domain model promotes the development of organisational narratives that can encompass the perspectives of multiple stakeholders and evolve over time.

The utility of cognitive work analysis for organisational storytelling may be demonstrated with a case study of its application to inform a narrative of the Royal Australian Air Force's doctrine and strategy. Alongside the general concepts of cognitive work analysis, work domain models of Australia's Air Power and Air Combat systems were important. This framework led to a logical characterisation of the meaning and interrelationships of a variety of air power concepts such as roles (e.g., strike, control of the air), missions (e.g., offensive counter air, strategic attack), and functions (e.g., force application, force protection). It also improved the rigour with which air power concepts are described, preserving clear connections between individual concepts, such as concentration of force, and broader constructs, such as principle of war. Moreover, by establishing a thread in the evolution of air power concepts, the coherence of the narrative was strengthened.

On the basis of this case study, it may be claimed that cognitive work analysis provided a useful means for organisational storytelling, having influenced the narrative of Australian air power doctrine and strategy. Its contribution to this narrative was unique, complementing the conventional operational viewpoint with a strong analytical perspective. Finally, this approach was shown to be feasible, having been achieved within specific schedule, personnel, and financial restrictions.

In sum, this paper extends the application of cognitive work analysis to organisational storytelling. The value of this approach is demonstrated with a case study involving the development of a credible narrative of the Royal Australian Air Force's doctrine and strategy. One limitation of this research is that it relies on a single case study. However, having documented this new application, further case studies are likely. Future research should also explore the suitability of cognitive work analysis for generating different kinds of organisational narratives.

Keywords: *Organisational storytelling, cognitive work analysis, work domain analysis, doctrine, strategy*

Submarine Force Deployment Modelling

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Abstract: Submarines are a valuable asset to the Royal Australian Navy (Defence White Paper 2013). A capable submarine fleet is able to perform various roles that contribute to outcomes that are desired by Defence in both peacetime and wartime. For example, it is able to perform covert surveillance and intelligence gathering, or to patrol and prevent passage of enemy vessels. Moreover, it is a potential deterrent to enemy operations. Key to the success of the fleet is its ability to sustain a presence in specified operating areas. A fleet that is unable to sustain a requisite presence will be less effective. It may not be in the right place at the right time in order to perform its roles or act as a deterrent.

The Submarine Force (SMFOR) Deployment model is a tool developed by the authors for DSTO which uses discrete-event simulation to analyse the achievable presence of given submarine fleets in different areas of operation. It has been used to support SEA1000 studies on Australia's future submarine options and Royal Australian Navy studies on the campaign readiness of the Collins fleet.

Central to the model are a submarine component and a mission component. The submarine component schedules submarines into their Usage & Upkeep Cycles (UUCs); a cyclic schedule of planned workup, maintenance and availability periods over the platform's life. At all times a queue of submarines which are ready to deploy is maintained. The mission component generates requests for mission deployment required to meet the target presence at random times during the life of the fleet. It looks at the queue of available submarines, matches these up with mission requests and simulates the deployments, using a number of customisable scheduling rules.

Inputs to the model include the fleet size, campaign duration, and individual platform characteristics such as endurance and maintenance cycles. The key output is the presence calculation. This is defined as the time-weighted mean number of submarines achieved on station over the duration of the campaign. In addition, various other fleet-level measures are produced. The Operational Tempo (OPTEMPO) is the number of days each boat spends at sea each year. Utilisation is the proportion of submarine uptime which is actually used for deployment, and spare availability is the residual amount of unused submarine uptime.

Several difficult modelling issues have arisen during the project. Modelling the effect of unscheduled maintenance has proven difficult. A sufficient dataset from which to infer accurate distributions of random defects is not available. Furthermore it is hard to guarantee that such data would adequately represent any future fleet which this analysis is performed on. Rudimentary models of unscheduled maintenance, such as reducing uptime by a constant proportion, have thus been considered.

The modelling of the UUCs is another challenge. These can vary for different types of submarines. Furthermore, they can be influenced by the locations of the home port and maintenance facilities of the submarines. They are well known for the Collins class but are difficult to predict for future submarine classes. Nonetheless, sensitivity analyses can be carried out to better understand how various changes to them will affect Australia's submarine capability.

A third difficulty is that the timings of campaigns and locations of the campaign missions are highly uncertain. In the model, the timings of the campaigns are represented as random variables with specified distributions (e.g. uniform). The locations of the campaign missions are informed by strategic planning scenarios, developed by Defence in consultation with Government.

This presentation introduces the problem of submarine fleet presence modelling, and presents the model, its methodology and implementation. The aforementioned modelling issues are explored, along with methods by which these have been managed in order to be able to provide timely and accurate advice to Defence.

Keywords: *Submarine, deployment, discrete-event simulation*

Modelling requirements for mission success prediction

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Abstract: The complexity of capability definition in the Defence environment necessitates a holistic modelling approach to ensure that critical existing elements and any new requirements associated with a particular system are encapsulated and maintained with a sufficient level of detail. Increasingly complex and expensive systems, specifically precision strike (air-to-surface) weapon systems, are being procured by Defence which require additional consideration of their integration with existing capabilities. As mission success is paramount for these systems, clarity can be gained by consideration of the entire capability in any system modelling.

The Defence Science and Technology Organisation (DSTO) have undertaken the Mission Success Prediction Capability (MSPC) project to provide greater insight into all stages of precision strike weapon mission planning to ensure efficient and effective use of these systems, and enhance the information available to decision-makers. MSPC employs a Model-Based Systems Engineering (MBSE) approach to conceptually model the operational and tactical level planning capability in Defence in response to its increasing complexity.

MSPC models a complex system of systems (SoS) where integration and adaptability is critical to the project's success. Modelling using MBSE has identified the operational activities currently being performed in precision strike weapon operational and tactical level planning, a number of gaps (user needs that are not currently being met, or only partially so) in the planning SoS, and an early understanding of integration risks. MBSE, through functional and system analysis, also provides the modelling requirements to enhance the current capability to meet the user needs. Existing systems and newly developed models, simulations, and/or tools are required to be integrated to allow a complete prediction of success for a given mission. MBSE also provides an inherent initial verification capability through simulation of the system's functional behaviour.

The knowledge model generated using an MBSE paradigm for MSPC has been used to automatically document a Description of Requirements (DOR). This knowledge model is the "single source of truth" for any further development progress and can be used to export other artefacts required by stakeholders, industry or subject matter experts. The DOR is a project specific artefact in the DSTO Engineering Management System, used to ensure that any modelling and simulation project has the required traceability and outputs for certification. The DOR is a combination of an Operational Concept Document and a Function and Performance Specification and therefore includes both concepts of operation and requirements for the new, amalgamated MSPC.

The MSPC project is being modelled using an MBSE paradigm and has provided Defence with a robust and adaptable requirements definition to ensure that any proposed capability enhancements are based on sound science, traceable to specific user needs.

This paper will provide further detail on the requirement for the MSPC project; the reasons for using the MBSE paradigm for the project and specifically during the project definition phase; the current outputs derived from the modelling process and the knowledge model produced during that process; and the critical modelling requirements identified.

Keywords: *Mission success prediction, decision support, mission planning, model-based systems engineering, system of systems*

Bridging the Gap: A Generic Framework for Behaviour Representation

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Abstract: Within the Defence Science and Technology Organisation the wargaming and simulation areas evaluate a range of operational issues from capability insertion through to the development of doctrine and procedures. To achieve this a range of simulations are used. While these simulations can be used in isolation several of them may be used in parallel/combination to provide a better understanding of the problem domain. This can be an issue when similar behaviours within the simulations differ due to the “stove-piping” effect found within each of the environments. To address this Land Operations Research Major Science and Technology Capability is developing a generic behaviour framework which provides not only a single reference point but a collaborative environment for all behaviour development in the simulations. In this environment individuals, with unique and separate domain knowledge, can contribute to and develop new behaviours without having to understand each other’s particular domain or specific simulation structures.

After examination of a number of framework options where three criteria were considered; concurrency, exclusivity and hierarchical depiction; it was found that through the use of a textual template linked to a Model Based System Engineering schema, specifically the extended Functional Flow Block Diagram (eFFBD), we have developed an information exchange mechanism which allows for the collaboration between Subject Matter Experts (SMEs) and simulation developers and also provides a framework which promotes the reuse of previously developed behaviour components. The framework allows developers to reference a library of previously created behaviours and use them in new behaviour representations within any simulation. The strength of this reuse capability is that components previously “validated” and stored within the library can be used to provide a more robust depiction of newly represented behaviours.

Different simulations have different strengths and weaknesses and are used complementarily in order to mitigate these weaknesses. The implementation of the behaviours within the simulations will not be identical, however their basic underlying structure will be similar such that the operational issues of interest can be compared. This underlying structure, derived from a single reference point, provides the analysts and users with increased confidence in the comparability of the output of the simulations.

The Generic Behaviour Framework proposed has provided an environment which both the SMEs and simulation developers can work collaboratively through the use of a textual template linked to a visual schema. The framework promotes the reuse of previously created behaviours and has increased the validity of the newly described behaviours. In turn, this has provided an increased confidence in the scenario output across simulations due to the use of a single reference point for behaviour descriptions.

Keywords: *Framework, generic behaviour, simulation.*

Assessing the impact of emerging technologies on the Australian Army

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Abstract: The relationship between emerging technologies and how the Army conducts its business is not a simple one. Army has a requirement for plausible emerging technology impact information in order to provide guidance for strategic planning and future development across the Army. An earlier study assessing emerging technologies on Army force structure highlighted the need for an ongoing program of work. In order to generate an ongoing program of traceable and consistent emerging technology information a process was developed which would support the nature of this work based upon the requirements of the Australian Army.

This project leverages off the emerging technologies work already conducted within DSTO, and couples with ongoing research and techniques that are well developed to produce an evolutionary ongoing process. An Army centric focus is used for analysis of plausible impacts of emerging technologies on generic Army functions over a rolling 30 year timeframe. In order to undertake this, a well-defined and consistent framework was required which would provide a common language to underpin the entire process. This framework was developed as a two-sided classification framework of emerging technology categories on one axis and generic functions of the Australian Army on the other. Using a framework of this nature has some limitations in that there are technologies which map into multiple categories; however it was found that this limitation was easily managed against the benefits provided by the ability of this framework to allow this complex space to be structured for study. The classification framework is presented as the first item in this paper.

The determination of plausible impacts of emerging technologies on the Australian Army is undertaken using a well-established qualitative technique called TOWS (Threats, Opportunities, Weaknesses and Strengths) which is designed to deduce outcomes and strategies from the combinations of these elements. TOWS is reliant on the strength and breadth of the Subject Matter Experts consulted and the ability of these experts and the analytical team to develop the outcomes/strategies and impacts. This plausible impact determination is the second focus of this paper, where the use of the TOWS method (as part of the larger emerging technology evaluation process) is presented with a sample of an impact analysis.

The plausible impact outcomes from this analytical process provide the Army with documented and researched outcomes and strategies resulting from the consideration of technology areas on Army functions, which may have impact on the way the Army conducts these functions in the future. These outcomes and strategies are provided to the Army for consideration as a part of their future strategic planning and development process. They cover the breadth of the external threats and opportunities as well as internal weaknesses and strengths for plausible technology impact on Army function and where the risk or opportunity may lie.

Keywords: *TOWS, impact analysis, emerging technology*

Investment Prioritisation

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Abstract: The aim of this study is the development of an investment prioritisation methodology to assist high level decision-making on prioritisation of Major Capital Facilities Program (MCFP) when program adjustments are required due to unforeseen circumstances such as funding reductions or new government-directed projects. The Defence estate is the largest and most complex land and property holding in Australia and significant annual capital investments in maintenance are required to repair or replace the existing facilities. Given the ever tightening financial constraints, there is a need for a prioritisation methodology to support the estate reinvestment strategy which would provide a strategically aligned, affordable, and sustainable estate portfolio.

We have conducted an initial review of the international best practices in estate portfolio prioritisation including *Better Practice Guide on the Strategic and Operational Management of Assets by Public Sector Entities (Australian National Audit Office 2010), the U.S. Base Realignment and Closure (BRAC)* studies, the *Military Health System Capital Investment Decision Model (CIDM)* developed by the U.S. Department of Defense and MITRE Corporation's *Portfolio Analysis Machine (PALMA).* Typically, Multiple Objective Decision Analysis (MODA) is used to develop a set of value measures for each investment alternative. Various alternatives are assigned numerical scores and the scores are combined using an additive value model, typically implemented as a weighted sum, to obtain the final priority score.

We found that the MODA linear aggregation techniques used to bring different criteria together to form the final priority score suffer from several critical limitations. Firstly, the additive value model implies mutual preferential independence between different evaluation criteria which is often difficult to achieve in practice. Secondly, the process of the assignment of numerical weights to different criteria, which is often done using tools such as the swing-weights matrix, is not straightforward and is very difficult to justify and get agreed on by all stakeholders. We find a non-linear aggregation method would be more appropriate to represent the complex relationships between criteria and also to handle sometimes conflicting stakeholders' exceptions.

We therefore propose to use natural language expressions to aggregate different measures. Our multi-criteria prioritisation model is based on fuzzy logic and is constructed as follows. First, we create a list of MCFP evaluation criteria linked to Defence capability and government strategic priorities. Each Major Capital Facility (MCF) is then ranked on a simple "Very Low" to "Very High" scale against each criterion. The input scores are then fuzzified using fuzzy membership functions. An "inference engine" is constructed based on a set of linguistic business rules. The business rules are provided by subject matter experts, hence the name. The business rules are in the form of 'if Project A's score against Criterion 1 is "High" and its score against Criterion 2 is "Low" then the project's priority is "Medium"'. The inference engine is used to evaluate all MCF projects and allocate a set of priority rankings to each. Finally, the priority rankings are defuzzified to give numerical scores which are used to build the project priority list. A prototype MCF prioritisation tool has been implemented in Microsoft Excel using MATLAB Fuzzy Logic Toolbox.

In summary, a simple and intuitive prioritisation framework for Defence estate investment prioritisation has been developed. Only two types of input are required from the end user: MCF scoring against each criterion, and a set of business rules. MCF scoring can be conducted by MCF support staff using objective project data. Senior decision-makers would only be required to formulate the subjective business rules. The suggested linguistic aggregation methodology is transparent, intuitive and tractable. It is also intrinsically non-linear and highly flexible enabling the use of custom business rules and exceptions. We note that a similar prioritisation methodology can also be applied to prioritise other project portfolios where a combination of objective and subjective judgment is involved.

Keywords: *Defence Estate, Major Capital Facilities Program, Investment Prioritisation, Multi-Criteria Decision Analysis, Natural Language Rules, Fuzzy Logic, Fuzzy Inference System*

Force Design for Adaptivity and Robustness- Feasible Scenario Spaces and Multi-scale Metrics

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Abstract: The generation and evaluation of options are critical aspects of force design. Option generation is constrained by many factors, including affordability, the impacts of legacy systems, and the limitations of currently held concepts and views. Even so, the number of degrees of freedom, and the ways they can be combined, results in a theoretical possibility space which is too large to search. Evaluation of the options generated is also problematic, requiring many assumptions to be made about the conditions under which the options may be employed and the tasks they would be required to achieve. Ideally one would seek a force design which achieved a balance between effectiveness in the most likely tasks, and the adaptivity and robustness to cope with a much wider range of possible tasks, under a wide range of possible conditions.

The traditional scenario-based method of evaluating effectiveness, with metrics such as loss exchange ratios, ammunition usage and system losses, while useful in providing scenario-specific insight into the strengths and weaknesses of the options being considered, this does not offer the means to explore the impacts of those options on force robustness and adaptivity. We argue therefore, that smarter approaches are needed to guide both generation and evaluation. We propose an iterative design process that permits effective and rapid exploration of the key aspects of the possibility space, informed by a comprehensive framework of metrics that addresses robustness and adaptivity as well as mission-specific effectiveness.

The iterative process starts with a plausible force design, and searches for the boundaries of acceptable risk. In this these boundaries are described in terms of generic dimensions that encompass the widest plausible ranges of conditions under which the force may need to operate. These dimensions include environmental parameters as well as adversary characteristics such as lethality and will to fight, and temporal parameters such as concurrency, and duration. Where unacceptable levels of risk start being incurred, the process then seeks to discover the adaptive potential of the force design through wargaming, also permitting the adversary force to react and adapt to the changes made by the blue force. The limits to further expansion of the domain of utility, yield an outer boundary, defining the Feasible Friendly Scenario Space for that force design option, within which the force design being tested can cope by exploiting both its core capability and its adaptive potential. The next step is to generate the new achievable force design options for the next iteration, and a natural way of doing this is to examine the failure modes of the force design option just explored, to identify plausible design changes that could remedy those failures, and repeat the process

It is also important to note that the ability to operate in additional parts of the scenario space is not the only reason one might choose to develop particular aspects of capability. Capability options can also restrict where the enemy might operate. This can be thought of in terms of canalisation. For example, having greatly superior reconnaissance and surveillance prevents the enemy from being able to conduct open battle forcing him to operate within complex physical and human terrain. Thus, the principal impact of a capability may be to restrict the freedom of action of the enemy. Just as with the feasible friendly scenario space this area defines the boundary of the scenario space in which the enemy can operate with acceptable risk. We refer to this as the Feasible Enemy Scenario Space. Thus, options are no longer simply compared with each other within defined scenarios but rather in terms of a struggle or coevolution between the FFSS and the FESS.

To support implementation of this approach, a multi-scale metrics framework is discussed which supports defining acceptable risk levels and the contours of the FESS and FFSS, as well as adaptivity and robustness measures in relation to the force design parameters. Such a characterisation of the force design problem we believe will support a more rigorous and comprehensive approach to the difficult trade-offs and design choices to be made.

Keywords: *Force design, metrics, scenario analysis, adaptivity, robustness*

EXTENDED ABSTRACT ONLY

ASW Search and the Effect of Speed

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Abstract: The search performance for an ASW ship has been extensively studied and generally increases both with its sensor detection range and its search speed through the water. On the other hand, sonar performance can vary significantly with speed, for example through the increase in ship self-noise with speed. So there is may be a trade-off between increased search coverage decreased detection range with increased speed. This effect is less well studied and is usually either neglected in search planning and tactical assessments of performance, or an artificial maximum speed is imposed. This paper discusses the analytical modelling of searching for submarines within the contexts of area search, barrier patrol and escort screening. This paper has developed a methodology within which the dependence of sonar performance on searcher speed can be considered analytically, based in turn on analytic models of ship self-noise and speed, transmission loss, and sprint-drift search. The ship speed that maximises the ASW search rate depends critically on the relationship between ship speed, ship self noise, array detection performance and ambient noise. Methodologies for incorporating target evasion into the analyses were also considered, but no attempt was made to do a complete two-sided analysis.

In the contexts of area search and barrier patrol is was found that in most cases the speed at which a search is undertaken is at least as strong a driver of overall success as is detection range. The success of a search or barrier mission can be strongly influenced by the strength of the relationship between the detection range of the sonar and the speed of the organic or towing platform. Furthermore, the optimal speed at which search should be undertaken is also strongly dependent on this relationship and tactical guidance should take this into account. In particular, even for reasonably small vessel speed/sensor range interactions the optimal speed for the search can be as low as the speed at which the self noise becomes larger than the ambient noise, with a commensurate decrease in expected search effectiveness. The effect is exacerbated if an evading target is considered. Another finding of the study was that losses in effectiveness due to any towed array downtimes during to ship turns can be significant for array settling times of the order of a few minutes.

In an ASW escort screening paradigm, this ship noise speed trade-off is particularly important as the escort must maintain an average speed of advance (SOA) at least as fast as the convoy main body. Ships operating passive Towed Array (TA) systems traditionally used a sprint-drift tactic to provide search capability. The analytic sprint-drift escort screen model developed in this paper optimises the parameters for the sprint-drift tactic for an active towed array. The model allows a direct comparison between the sprint-drift tactic and the effectiveness of an escort screening continuously at the convoy speed of advance. While performance data and tactics for such systems are generally classified, this paper presents analysis across a range of representative tactical and sensor parameters. The results suggest environmental and sensor performance criteria generally determine which of the sprint-drift or continuous search tactics provides higher escort effectiveness. However, there are some criteria under which the most effective escort tactic depends strongly on details of the escort problem. The results also indicate that system performance and environmental knowledge are important factors in choosing the appropriate tactical parameters to maximise sprint-drift escort screen effectiveness.

A simple simulation also showed that non-omnidirectional sensors can be approximated by the analytical models in some cases, however more detailed simulations should be undertaken using more complex sensor azimuthal and time-to-detect performance paradigms to properly bound the validity of the analytical models.

These results highlight the importance of knowledge of these system and environmental parameters in the choice of effective escort tactics.

Keywords: *Anti-Submarine Warfare, Operations Research, Modelling, Search Theory, Escort Screening, Area Search, Barrier Patrol.*

EXTENDED ABSTRACT ONLY

Path Analysis of Infantry Combat during Battle of Kursk

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Abstract: Lanchester equations have been an important tool for analysing combat for many years, but these equations in their various forms have focused on modelling only combat attrition. Some work has been done to model broader aspects of combat and to combine these with the Lanchester equations. These studies have shown that the Lanchester equations can be incorporated into a more generalised model of combat, specifically one that is described qualitatively with path diagrams.

It can be shown that path diagrams can be constructed from a statistical analysis of historical combat data. The data used is from the battle of the Kursk which occurred on the German eastern front in the latter stages of WWII in 1943. The methodology of constructing the path (influence) diagrams from observational data makes use of multiple regression analysis to identify the regression coefficients for each of the exogenous or independent variables and hence the influence these have on the endogenous or dependent variables. This methodology is known as path analysis, and is a special case of structural equation modelling (SEM).

The data used for the analysis was obtained from the KOSAVE database which is an extensive collection of historical data of the battle of the Kursk. This battle took place in the vicinity of the city of Kursk (approximately 450 km south of Moscow) in what was the German eastern front. The battle occurred in the latter stages of World War II in July and August 1943.

Using the database and other historical analyses it was possible to identify the main infantry units on each side for the battle. It was assumed that those infantry units would have engaged enemy infantry units directly opposing them; some subjective decisions were made to identify which units on the German side were engaging which units on the Soviet side. Those infantry units that were co-located with armour units (i.e. tanks) were excluded from the analysis.

In general the hypotheses to be tested are:

- The shooter's weapon firepower usage is negatively correlated with own casualties;
- The shooter's weapon firepower usage is positively correlated with enemy casualties.

These can be applied to the partitions of the data where each side (German and Soviet) or shooter is in either an attacking posture or a defending posture. The result is eight possible hypotheses which correspond to the eight partitions of the firepower usage and casualties data (i.e. which side, what posture, and who is the casualty). These hypotheses can stand alone or be paired to represent complementary equations of a combat attrition model, for example Germans in a defensive posture and Soviet casualties paired with Soviets in an attacking posture and German casualties.

The results from the path analysis show that not all weapon firepower usage is relevant to the casualty figures. In several of the hypotheses it was found that the casualties did not have any significant relationship to any of the weapon firepower usage of the opponent. Although this appears to be a less than satisfactory result, it would be worthwhile to try to identify latent variables or constructs that are not directly observable but which are related to the observable data and which can be used to explain the casualty variable. It may also be worthwhile to identify other observable data that could be included in the regression analyses; one additional variable, unit movement, was identified during the data preparation phase but was found to be unsuitable as infantry units did not make large movements from day to day of the battle unlike the armour units.

Keywords: *Lanchester equations, path analysis, path diagram, SEM, influence diagram, multiple regression*

The Simple Dependency Ranking System – A novel method for defence capability prioritisation

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Abstract: The prioritisation of capabilities is an important activity in Defence, as decision-makers grapple with shifting factors such as costs, schedules and tasking in the face of a finite budget. While a number of methods for prioritisation exist, they usually require large amounts of input data, often in the form of judgments, and thus can be computationally and resource intensive, particularly when accounting for multiple criteria, different stakeholder perspectives and interdependent issues. A novel approach has been developed, namely the Simple Dependency Ranking System (SDRS), which provides an alternative method of arriving at a prioritised list that also takes into consideration the most important dependencies between capabilities.

The methodology of the SDRS was specifically designed to be simple and transparent. The approach essentially consists of creating two ranked lists: one of individual elements and one of pairs of elements (that correspond to element dependencies). By making assumptions with respect to the relative scoring of the ranked elements, both within each list and across each list, a final score for each element can be determined. The result is a priority ranked list that has taken the most important element linkages into account, according to the stakeholders. While initially originating from social choice theory, the SDRS is shown to be related to established methods in requirements prioritisation and network analysis.

By virtue of its design principles, the method has additional advantages: it is relatively quick to perform, it requires minimal data in its operation, it has the potential to be scalable, and it can be performed by individuals or groups. In addition, the explicit articulation of element dependencies permits the generation of a partial systems diagram that should reflect the core connected clusters of the system. As it is not comprehensive, it is unlikely to be the only method used in managing a portfolio of projects such as the DCP. However, it may be useful as a quickly repeatable approach to identifying areas of similarity and difference and a framing technique for group discussion and decision-making.

As well as introducing the method, this paper also reports on an initial experiment devised to explore and test the approach. Twelve volunteers took on roles as Defence domain stakeholders (Air, Maritime, Land and Joint) and prioritised a set of thirty-two Defence capabilities (eight from each domain). Two questions were of specific interest:

- Does the process of identifying pairs improve the consistency of the final rankings amongst players?
- Is it adequate to simply average individual responses, rather than attempt to achieve a group decision?

The results of this limited experiment show some positive evidence for both questions i.e. some convergence towards an "agreed list" and the high similarity of averaged individual results with the team decision. While only preliminary, the initial results are encouraging and indicate that the method deserves further investigation and potential refinement.

Keywords: *Keywords: Prioritisation, defence capabilities, systems, dependencies*

Differential Analysis of Text-Data through Sentiment Scoring, Applications in Defence Capability

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Abstract: Text Analysis continues to pervade Defence Science and increasingly so in the surveillance domains given the rise of the Internet, SMS and especially social media networks. Consequently new research is active in areas to address such developments. In contrast, one important research question that has received comparatively little attention is that of the task of differential analysis for text data. Our interests in this area are the applications to current defence capability questions. Given the accepted notions of a "whole of force" ADF and in addition the notions of Joint Operations or Joint Warfare, its important that defence capability is similarly examined through a collective all inclusive process. In part, the Joint Decision Support Centre in DSTO strives to address this point. That is, to offer a collective environment for ADF Stake-Holders groups in which matters of defence capability might be examined via workshop processes. Our data sets are text data collected at such workshops, however the algorithms we propose are not limited to such data.

The approach we take (to addressing differential analysis) in this work is to examine sentiment scores of the text responses elicited through defence capability workshops. Sentiment scores are widely used in opinion mining, see for example the well known resource SentiWordNet at the URL `http://sentiwordnet.isti.cnr.it`. The (several generations) history and details of SentiWordNet are discussed in the literature.

The basic task here is to score words (numerically) as positive or negative. An additional challenge is to infer (via sentiment) if text is subjective or objective. To score sentiment one typically requires a lexicon. NICTA has developed its own proprietary sentiment score lexicon, which has been applied in this work. A numeric score for a given text idea/response/entry is determined then converted to a colour with the obvious extrema of; strong red for extremely/max negative sentiment and strong green for extremely/max positive sentiment. We first consider this at a word level only (in the Key Phrase section below we also apply sentiment scores to phrases). Recall that we denote a document D^i by the set, $D^i \triangleq \{w_1^i, w_2^i, \dots, w_{L^i}^i\}$. Further, write $\rho(\cdot) : V \to [-1, 1]$ for a sentiment function, which maps a given word in the lexicon to a real number in the shown range. In our sentiment analysis we consider two types of computation, the first is a sentiment score per document, the second involves a user query, with sentiment then computed around all instances of the given query. In the first case we compute the sentiment score of the document Sent.(D^i) by a sum, that is, Sent.$(D^i) \triangleq \sum_{j=1}^{L_i} \rho(w_j^i)$. The calculation shown is evaluated for all documents in the corpus $\{D1, D^2, \dots, D^I\}$. Subsequently, each score is rescaled to $[-1, 1]$ through the normalisation Sent.$(D^i)/M$, where $M \triangleq \max_{i \in \{1,2,\dots,I\}} \Big\{|\text{Sent.}(D^i)|\Big\}$. We also develop calculations for sentiment scoring by context based upon uers-submitted query words.

This article develops schemes for differential analysis of text data taken as arising from different (possibly dependent) sources, each of which address a common topic. For example, suppose a defence capability workshop examined the role of Australia's Future Submarine as a strategic deterrent. Further, suppose this workshop received text contributions (on the above topic) from three different stake-holder groups, for example, the Australian ARMY, the Australian Air Force and the Australian Navy. An immediate question is this, are these text contributions different, if different how might we numerically score/rank such differences using the text-data as information? In general differential analysis for text data is a relatively new area of research, indeed most common software packages for text analysis do not address the issues just described. In this work we propose a sentiment scoring for differential analysis. This algorithm is demonstrated both in a raw-score form and scoring against user-supplied queries. Additional examples are given when scoring key phrases.

Keywords: *Natural language processing, Text sentiment, Key phrase estimation, Algorithmic text analysis, Defence applications, Defence capability, Topic estimation, Latent Dirichlet allocation*

Estimation and Analysis Schemes for Collections of Discrete-Time Integer-Valued Arrival Processes

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Abstract: Counting processes (in general) describe the integer-valued evolution of some phenomena of interest, for example: the arrival of emails at a file server, the number of so-called "twitter" messages posted on a website, or, the arrivals of illegal refugee vessels detected in a given country's waters. While such processes have broad applications, we are particularly interested in the analysis and modelling of arrival processes for illegal refugee vessels in Australian waters.

The canonical or default model for a counting process is the celebrated Poisson Process. This stochastic process is a continuous-time process and arises directly from two basic properties; stationary and independent increments. In this article we are concerned with a variation on a Poisson process, where continuous time is replaced by a discrete-time index, such as a date-stamp or an index multiple of fixed increment of time $0 < \Delta_t$. We assume our arrival processes are random time series of modulated Poisson random variables. Further, it is assumed that rate functions for these time series are functions of some other modulating processes, such as a Markov chain. Here the state of the Markov chain might indicate rate levels, such as *low*, *medium* and *high* intensity of expected arrivals. The algorithms we present here are estimation schemes for the hidden modulating process observed through the Poisson random variable (RV) time series. In particular we examine the simulation and estimation of correlation between arrival processes. Here, correlation is conveyed to the observation sequences through the Markov chains, whose realised states determine the sequence Poisson intensities. To compute an exact filter for time series of Poisson observations we apply the method of reference probability, made popular in Electrical Engineering and Applied Mathematics. This approach leads to recursive estimation schemes. For our partially observed state dynamics we consider a family of homogeneous discrete time Markov chains. The state of these chains in turn determines a unique Poisson rate function describing the measured time series.

We suppose that at each regular epoch, indexed by an integer k, we observe an integer valued random variable $Z \in \mathbb{N} = \{0, 1, 2, \dots\}$. Here the symbol Z represents a Poisson random variable, whose distribution parameter depends upon the state of a Markov chain X in a known way. This dependence is through the Poisson parameter, with mapping $\lambda : X \in \{\boldsymbol{e}_1, \boldsymbol{e}_2, \dots, \boldsymbol{e}_K\} \to \mathbb{R}_+ \cup \{0\}$.

The possible states (here) of λ are taken to be, $\boldsymbol{\lambda} \triangleq \{\lambda^1, \lambda^2, \lambda^3\} \equiv \{\text{Low}, \text{Medium}, \text{High}\}$. For brevity we restrict our attention to three possible states for the Poisson parameters, low medium and high intensity. Note that the state loosely referred to here as low, may be set as $\lambda^1 \approx 0$. Consequently, the discrete time model for a Poisson random variable time series is itself a discrete-time stochastic process $\lambda_k \triangleq \langle X_k, \boldsymbol{\lambda} \rangle$. The random variable Z is a Gauss-Markov modulated Poisson random variable. The distribution of Z_k has the form:

$$P(Z_k = i) = \frac{1}{i!} \langle X_k, \boldsymbol{\lambda} \rangle^i \exp\Big(-\langle X_k, \boldsymbol{\lambda} \rangle\Big), \qquad i \in \mathbb{N}. \tag{1}$$

Remark 1. *In our full treatment of this estimation problem we use well known reference probability methods and thereby compute (the so-called) un-normalised dynamics. This approach avoids numerical instabilities with small Poisson rates.*

Our task is to estimate the latent Markov state giving rise to the Poisson times series and in so doing, establish a means for forecasting and correlation between different arrival processes.

Keywords: *Arrival processes, Counting processes, Change of measure techniques, Correlation*

Land Combat Vehicle Terrain Accessibility and Impacts on Conduct of Operations

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Abstract: Protection, Mobility and Lethality are the three key characteristics of Land Combat Vehicles (LCVs). Each of these characteristics is multi-dimensional with many interdependent elements. The individual characteristics need to be fully understood before considering the complex relationship between the three characteristics.

The focus of our work is on Mobility from a close combat, tactical and operational perspective. The overall aim is to evaluate Mobility in terms of terrain accessibility and manoeuvrability of individual LCVs and mounted combat teams. A particular requirement is to analytically differentiate between similar vehicles and different drive-lines, noting that the vehicles to be compared are potentially within the same mobility category, as defined by defence standards. This will assist in supporting capability acquisition decisions.

Our research approach is to identify, describe and then study elements of terrain accessibility and manoeuvrability, both individually and in connection with other elements in order to quantify mobility performance characteristics. Our aim is to provide a high level view of mobility by developing terrain accessibility and manoeuvrability factors and indicators using Army doctrine, well known empirical analysis documents, such as the NATO Reference Mobility Model II (NRMM II), and parametric analysis to expand beyond the aspects of vehicle ability, such as Mean Maximum Pressure (MMP), Vehicle Cone Index (VCI) and Draw Bar Pull (DBP).

So far we have developed a visual tool which shows how aspects of vehicle ability combine to predict terrain accessibility and manoeuvrability. This has been done by generically describing the different dimensions of terrain and identifying the properties and characteristics that shape/influence manoeuvrability. Not surprisingly, initial analysis suggests that vehicle weight and ground contact area, as well as soil type and moisture content, significantly impact terrain accessibility and manoeuvrability. Other factors and indicators which are the focus of our ongoing investigation are the relationships between the vehicle and obstacles, such as hydrological features and vegetation.

Further work is required, including conducting a sensitivity analysis on the terrain accessibility and manoeuvrability factors and indicators, to determine the mobility performance measures/descriptors that can be used to differentiate between vehicles. Once individual LCVs can be assessed we plan to expand our research to a scenario-based assessment to consider how individual vehicles work together within a mounted combat team. It may then be possible to further extend the scenario-based assessment to include an assessment of the capability consequence (both opportunities and constraints/limitations) that result from differences in the mobility capabilities of friendly and adversary vehicles and combat teams.

The overall outcome of this research will assist in understanding capability gaps and the needs and requirements for future LCVs.

Keywords: *Terrain Accessibility, Manoeuvrability, Trafficability, Mobility, Land Combat Vehicle*

Exploring the role of Joint in Force Design

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Abstract: Defence doctrine defines joint as "activities, operations and organisations in which elements of at least two Services participate." The last 25 years have seen the ADF become proficient in the conduct of joint operations; however, the ability to master future joint operations will require 'jointery' to be extended to force design and capability management within the wider Australian Defence Organisation (ADO). The authors postulate that joint constitutes an operating space of sorts, within which ADO branches (organisational entities) conduct activities that range from being tactical and 'proximal' to front line operations or concerned with their planning ahead of time, or more distally related still, concerned with force design or capability planning years in advance.

This presentation introduces the joint space as a means of bringing together existing theories related to joint within three inter-related conceptual constructs: organisation and coordination, social capital and optimisation of socio-technical system. Organisation and coordination draws primarily on command and control and organisational sciences. At its core is the trade-off between specialisation to achieve organisational mission versus the need to invest in coordination in order to collaborate with other organisations. Social capital might be referred to in this context as joint capital, and it relates to the collective capacity created through formal and informal networks, joint experiences, culture and joint education and training. It is the degree to which the organisation can draw on previous experience and understanding of joint to achieve joint actions and effects. Social capital draws on organisational psychology and behavioural psychology disciplines. The third construct is optimisation of socio-technical systems, which introduces a systems perspective of joint, introducing the concept of emergent behaviour to explain effects present only at the joint level. In addition, this construct brings out the link between technology and the human, drawing on network centric warfare literature.

A conceptual model of joint has been developed which allows each of the multidimensional joint constructs to be reduced to a single dimension, thereby allowing the authors to assign values to each of the constructs. Furthermore, we have explored the resultant three dimensional joint space by placing individual organisational entities within this space and looking for correlations between entity clusters and properties of the entities within the cluster. An understanding of how joint attributes correlate with joint activities and outcomes, such as force design, should allow Defence to specifically tailor approaches to integration and coordination that enhance joint outcomes.

The presentation will review the literature that underpins joint, outline the joint space and demonstrate how it has been instantiated in an empirical study of ADO branches using a modified Situation Awareness Rating Tool applied as a survey instrument to 100 One-Star Officers. The paper will conclude by presenting the results from data collection, identifying several modes of joint interactions and their relationship to joint outcomes relevant to force design.

***Keywords**:* *Joint, management science, conceptual models, systems analysis, Australian Defence Force*

Validity Checking of Combat Models: a Falklands War dataset

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Abstract: External validity assessment of mathematical and simulation combat models suffers from the paucity of accurate two-sided sets of combat data. Valid combat models need not repeat the outcome of any particular historical battle. After all, the realized outcome of a battle was, before the battle, only one of many possible outcomes in a probability density function. To judge the external validity of a combat model one needs to compare its predictions to many historical battles to see whether they fall within the empirical distribution function generated from these many observed values. This requires a record of the appropriate predictor variables from historical battles. Since the infantry crisis of the latter 19th Century, arising from the increased range and accuracy of artillery and firearms, infantry has sought to avoid the expanded zone of annihilating fires through use of cover and concealment and, when this is impossible, to work as part of a combined arms team with engineers to speed their crossing and with artillery and direct fire support to suppress enemy fires and deliver concealing smoke during their time in the zone. However, amongst those data sets that exist, there is typically insufficient information about the combining of arms, the geography of the battlefield and the times that units are exposed to fires to generate appropriate predictor variables. Inappropriate temporal aggregation of data (often the smallest temporal unit is the entire battle) frequently obscures the true exposure to fires of units and conceals the importance of the timing of suppressive fires.

We present a data set of five land battles from the Falklands War gathered from historical source documents. We report the information normally given in historical data sets used to assess the external validity of combat models: number of combatants and casualties. However, particular care is given to accurately recording the length of battles for the units involved and nature of combined arms support to the infantry.

Although casualties were greatly reduced when suppressive fires were used this appears due to the resultant reduction of the length of the battle rather than a reduction in the rate at which soldiers are injured or killed. Furthermore, when combat support actions are included, the length of the battle was considerably different for the infantry on either side. British artillery, naval gunfire and airstrike preparation of the battlefield led to Argentine infantry being exposed to fires for considerably longer than British infantry. Poor placement of Argentine defensive positions on the forward slopes of hills maximised their exposure to British fires and lack of combined arms support meant British infantry, and their fire support, were not effectively suppressed, neutralised or destroyed. The most favorable loss ratios for British forces were achieved when this support crescendoed immediately prior to the British infantry assault and was combined with a careful engineering preparation of the assault routes and plentiful direct fire support from armoured vehicles out of range of Argentine anti-armour weapons.

Even though Argentine infantry were conscripts there was a consistent pattern of their morale breaking only after two fifths of a unit had been killed or incapacitated. It is likely that their placement in defensive fortifications made Argentine soldiers more likely to fight to the death than they would otherwise have been. While the disasters of the Battle of the Frontiers in 1914 or Japanese Banzai charges in 1944-45 show that superior morale cannot cross the zone of annihilating fires without cover, concealment and suppression -- morale is still an important and under-modelled issue. Almost all victories are won by breaking the will of the enemy to fight rather than by killing them on the battlefield. Combat models typically assume that fight-to-the-death scenarios produce casualty results similar to reality even though, except in the face of the most barbarous of enemies, most "casualties" surrender. More sophisticated combat models, taking into account the temporary panic and confusion caused by offensive support closely followed by infantry assault or the reversal of fortunes from a vigorous counterattack closely following the seizure of objectives, require accurate temporal information to allow appropriate predictor variables to be developed.

Use of combined arms and offensive support appeared to reduce the length of these battles rather than the casualties per time period. Geography made defenders more vulnerable. Five data points are insufficient to provide a test of combat models but they are sufficient to reinforce the need for information on combined arms and geography as well as appropriate temporal aggregation in historical datasets.

Keywords: *Historical combat dataset, combined arms combat, external validity assessment*

Operations Research Meets Science Communication

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Abstract: The goal of most, if not all, applied operations research is to inform in order to create a change. Most problem solving methods recognise this with a final step such as "communicate results" but usually provide scant advice about the factors to consider when promoting success in communicating science effectively. Concerns expressed internally within the Department of Defence suggest that this communication may not be fully effective.

It is important that operations analysts communicate and engage throughout the problem solving process in order to ensure that the correct problem is solved, stakeholder buy-in is achieved and relevant data is obtained. Each instance of communication will vary in that each will have a different purpose, different audience or different message.

Science communication is concerned with communicating messages relating to science, engineering or technology. Four models of science communication have developed – Deficit Model, Context Model, Lay-expertise Model and Engagement Model. Each model suits a different communication context and can inform the way in which an analyst or scientist might engage a decision-maker or stakeholder through the problem solving process.

Effective communication is achieved when the audience considers, not necessarily implements, the information provided. A number of factors can be considered in planning each communication activity to ensure success. These include understanding the audience, provision of timely information, and clear framing of information. Key to knowing the audience and clear framing is to recognise cultural differences between the scientist and the audience as well as differences within the audience. Each message should also be framed in terms of the organisation's objectives and the implications of alternatives rather than simply providing scientific outcomes of the study. Planning for this communication is part of task planning and is central to successful communication.

Keywords: *Science Communication, Operations Research, Grounded-Theory*

Analysis Support for Land 19, Phase 7: an Integrated Approach

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Abstract: Project Land 19, Phase 7B (Land 19-7B) seeks to develop a Ground Based Air and Missile Defence (GBAMD) capability to enhance the level of force protection afforded to the Australian Defence Force.

DSTO provides a range of support to new Defence capability projects including an assessment of technical risks and technical studies in support of options analysis, requirements definition and the decision making process (Australian Government 2012a).

This paper describes the analysis support provided to Land 19-7B focusing on the underpinning philosophy and methods. A Model Based System Engineering (MBSE) methodology has been used to derive capability definition documents, encompassing the Operational Concept Document (OCD) and Function and Performance Specification (FPS). This same MBSE approach has been adopted to provide rigour and traceability to both the design of experiments, and the development of the modelling, simulations and analysis (MS&A) capability. The MS&A capability being developed has leveraged existing MS&A frameworks and portable component models.

The significant client involvement in the MS&A design is vital to ensure appropriate representation of the scenario vignettes and experiments. As the capability definition matures and the client questions change, the approach taken will ensure that the appropriate level of analysis can be conducted to inform the Government.

Keywords: *Model Based Systems Engineering (MBSE), Model Based Concept Design (MBCD), capability development, modelling and simulation, experiment design, client engagement*

On the analysis and aggregation of expert opinion, applications in Defence Science

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Abstract: This article identifies and examines a collection of mathematical techniques for the aggregation of a collection of Expert Opinions elicited in numeric form. In most cases Expert Opinions are given as one of: point probabilities, probability distributions, or ranges of probabilities corresponding to events of interest (alternatively such ranges might be referred to as probability intervals of the form $(a, b) \subset [0, 1]$ etc). Indeed algorithms exist for each of these three classes, here however, we direct our attention to the case of expert opinions given as probability intervals. Our contributions are based initially upon an interesting algorithm due to Dwight Freund and Umesh Saxena, see [Freund & Saxena, 1984]. Freund and Saxena's article develops an algorithm based upon a constrained estimation task, with one of several criteria being the maximisation of entropy. Essentially this means computing a consensus amongst the experts, or, alternatively, computing the aggregated probability distribution in "least disagreement" amongst the collection of experts. In this article we explain Freund and Saxena's algorithm in detail and identify and establish several of its important technical properties. In addition to this contribution we extend Freund and Saxena's algorithm to include the maximisation over a relative entropy constraint. This extension provides the practitioner with a new capability to compute the aggregate (consensus) distribution relative to a given distribution. Our main aim in this article is to indicate the potential value of expert opinion aggregation and analysis techniques to applications in Defence Science.

In general the modern world commits substantial effort and resources into the tasks of generating experts, or highly skilled specialists. In contrast, comparatively little effort is applied to the task of effectively analysing and combining experts. Further to this, many hideously complex problems have emerged in the modern world which are well beyond an individual and in some cases even beyond reliable modelling. In such scenarios it is quite common to appeal to a finite collection of experts. Most importantly of all, how does one effectively analyse and ultimately aggregate these Experts' opinions ? Suppose the expert's probability intervals are all $[a, b] \subset [0, 1]$.
Further, suppose now that we compute the following intervals,

$$a_j^* \triangleq \min_{j \in \{1,2,\ldots,K\}} \{a_j^1, a_j^2, \ldots, a_j^N\}, \tag{1}$$

$$b_j^* \triangleq \max_{j \in \{1,2,\ldots,K\}} \{b_j^1, b_j^2, \ldots, b_j^N\}. \tag{2}$$

Here the number a_j^2 is the lower number of the probability interval provided by expert 2 concerning event j. Similarly the number b_j^2 is the upper number of the probability interval provided by expert 2 concerning event j. Consequently we generate a collection of K intervals, $\{[a_1^*, b_1^*], [a_2^*, b_2^*], \ldots, [a_K^*, b_k^*]\}$. Note that these derived intervals are all inclusive in that any one of them will contain each of the corresponding intervals for all N experts. Finally, to compute our (optimal and "consensus") singular probability density we formulate a constrained optimisation problem based on absolute Entropy and relative entropy.

Keywords: *Aggregation of expert opinion, Probability intervals, Optimization, Maximum entropy, Relative entropy*

Structured Time-Independent Capability Options Analysis

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Abstract: In Australia's defence capability development process, needs and requirements are scoped, bounds and constraints applied, and then a series of data collection and analysis activities are held with the threads of logic brought together close to a pre-defined deadline. Consequently, the "quality of argument" for a solution is low throughout most of the analysis campaign but increases rapidly when all threads of logic come together close to the deadline (Figure 1a). Occasionally, however, capability option decisions are moved forward on short notice, and/or constraints and options change frequently over the course of the analysis. It is therefore sometimes important to be able to present the 'best' option at all times. This complex problem has led to the development of the Structured Time-Independent Capability Options (STICO) analysis methodology, which aims to continually maximise the quality of argument, i.e. account and have evidence for the 'best' option at all times until the (unknown) decision point occurs (Figure 1b).

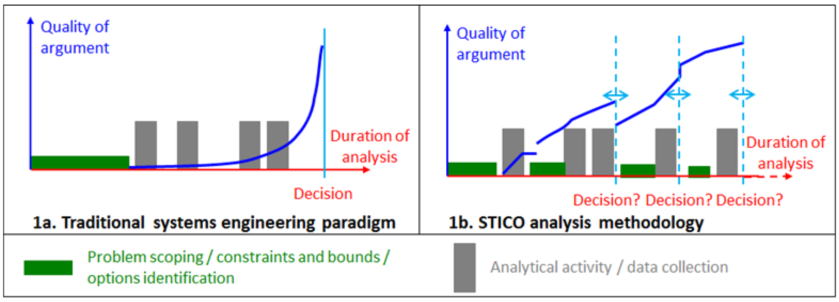

Figure 1: Classical options analysis versus STICO analysis

The methodological problems addressed by STICO analysis are: changing needs and requirements; an inhomogeneous group of numerous stakeholders; prior knowledge and potential preconceptions by stakeholders and analysts alike; the potential for options to be added or removed during the life of the analysis; the presence of qualitative as well as quantitative performance data for the options; and the existence of varying levels of data confidence. STICO analysis ranks options using ELECTRE III – a Multi-Criteria Decision Making outranking technique that allows representation of multiple quantitative and qualitative criteria and incorporates confidence measures. Option ranks are reviewed using the continuous critical feedback triggered by either event-based inputs (external to the analysis team) or continual assessment inputs (driven by the analysts' boundary critiques). Evidence contradicting the option ranking is actively sought and analysts use triangulation with other methods to increase confidence in criteria evaluations. Options are presented visually using Tarax diagrams: an extension of spider web plots wherein each option is represented by a dandelion (Figure 2). The seeds represent the dimensions of the problem space; their length indicates the 'value' of the associated criterion and their width depicts the confidence in that value. As the project steps through time, the Tarax diagrams change. This way both the 'best' solution to the problem can be seen and justified at any point in time.

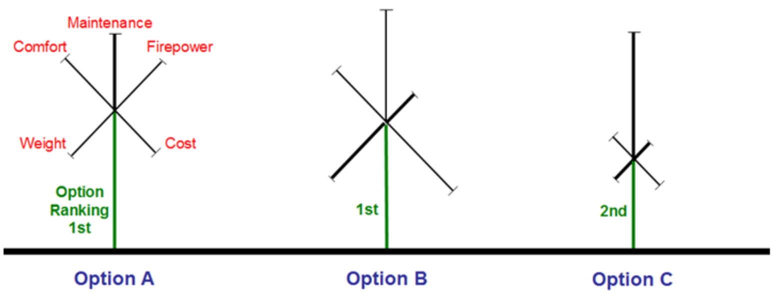

Figure 2: Example Tarax diagrams

Keywords: *Capability option analysis, Multi-criteria decision making, Boundary critique, Tarax diagrams*

Modelling the Relationship between Duration and Magnitude of Changes in Asset Prices

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Abstract: This paper examines the relationship between the duration and magnitude of changes in asset prices using ultra-high frequency data. The literature on modelling conditional duration of changes in asset prices focuses mainly on the past durations without utilising any additional information. Similarly, the conditional models for changes in asset price do not take into account the duration of the changes. Given both variables contain information regarding market movement and investors' sentiment, it seems natural to test if past durations contains any information for the magnitude of price changes and if the magnitude of previous price changes contain any useful information in predicting the duration of the next price change.

This paper proposes a new model that captures the interaction between duration and magnitude of changes in asset prices, and thus provides a convenient framework to test statistically the existence of such relationship. The model is flexible and contains various well known models as special cases, including, the Exponential Generalised Autoregressive Heteroskedasticity (EGARCH) model of Nelson (1991) and the Logarithmic Conditional Duration (Log-ACD) model of Bauwens and Giot (2000). Despite having the EGARCH model as a special case, the objective of the model is not trying to model conditional duration and conditional volatility jointly. As shown in Ghysels and Jasiak (1998), modelling conditional duration and volatility jointly is technically challenging. This is due to the fact that volatility is defined over a regular sampling frequency but duration is defined over irregular time intervals. Given GARCH model is not generally closed under temporal aggregation, this creates a challenging modelling problem. The aim of this paper is to avoid this challenge by not modelling the conditional volatility, but instead, model the dynamics in the magnitudes of price change. The paper argues that since volatility is a function of the magnitudes of price change, testing the relationship between duration and the magnitude of price change provides an indirect test on the relationship between duration and volatility.

The paper also obtains theoretical results for the Quasi-Maximum Likelihood Estimator (QMLE) for the proposed model. Specifically, sufficient conditions for consistency and asymptotic normality are derived under mild assumptions. Monte Carlo experiments also provide further support of the theoretical results and demonstrate that the QMLE has reasonably good finite sample performance.

The paper then applies the model to nine different assets from three different asset classes, namely two exchange rate, two commodities and five stocks. The two currencies are Australia/US and British Pound/US exchange rates; the two commodities are Gold and Silver and the five stocks are BHP, Rio Tinto, CBS, ANZ and Apple. The sample spans from 4 January 2010 to 30 December 2011 with an average of 100,000 observations.

Keywords: *Intra-daily data, duration, volatility, price change*

Testing intra-daily seasonality using Maximum Entropy Density

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Abstract: The objective of this paper is to test for intra-daily seasonality using Maximum Entropy Density (MED). Specifically, this paper attempts to investigate seasonal patterns over weekdays and through the hours of a given trading day. The MED estimation is essentially a data driven technique which produces a density function. A comparison of MEDs across different time segments of the data allows one to test for the existence of intra-daily seasonality. More importantly with regard to comparisons, an MED presents a richer source of information compared to a singular metric such as the mean or variance. In other words, such a comparison enables one to measure different facets of a distribution. In particular, different moments of the distribution. Repeated patterns in one or more moments between time segments over a period implies the presence of intra-daily seasonality.

MED estimation techniques assume that a random variable is independent and identically distributed (iid). This condition ensures that consistent estimators are produced. However, return data has a correlation structure and as such the observations are not iid. It is proposed that this correlation structure be filtered out prior to the construction of the MED using an ARMA(1,1) - GARCH(1,1) model.

The overall methodology of this paper is as follows. A data series consisting of returns is segmented into weekdays. For example, all the Mondays are extracted from the data. Each Monday segment is referred to as a block. Note that there is a time discontinuity between two consecutive Monday blocks. This has important implications with regard to filtering the correlation structure. An ARMA(1,1) - GARCH(1,1) model is only implemented at the block level since time is continuous within the block. The residuals are standardised and checked for autocorrelation. A MED is computed on the residuals of each block. The first four moment constraints are used for the MED construction. As such, there are four MED parameters i.e. λ_i where $i \in 1, 2, 3, 4$. Subsequently, the mean values for each λ_i are computed over all blocks corresponding to a given weekday. These values represent the final MED parameters for a given weekday. For example, the λ_i values are averaged over all Monday blocks to get the overall MED parameters for the Monday segment. Testing for intra-daily seasonality is done in two parts. Firstly in order to verify the structure of the resulting MED, tests are conducted to assess if the resulting mean values are significantly different from zero. Secondly in order to check for intra-daily seasonality, tests are conducted to assess if the resulting mean values are significantly different across the weekdays. Significant differences in the mean values of λ_i across weekdays indicates that the distribution of returns changes during the week. This pattern over a period of time corresponds to intra-daily seasonality. This process repeated to check for intra-daily seasonality across different time intervals over a trading day.

The results indicate that one of the mean values of the MED parameters for Wednesday is significantly different from the rest of the weekdays. Similarly, one of the mean values of the MED parameters is significant for the 12p.m.- 2p.m. interval.

Keywords: *Maximum Entropy, Moments, GARCH, Time of day effect, Weekday effect*

Spatial Diffusion of Air Conditioners and Time-Varying Price Tariffs in Residential Housing

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Abstract: In order to plan for the major changes to extra loads and storages on an electricity distribution system with temporally and spatially variable capacity, it is critical to be able to project the magnitude, rate, and location of technology/appliance uptake by consumers at a fine spatial scale. This paper presents an application of a methodology, based on diffusion modelling, for estimating the uptake of air conditioners and time-varying price tariffs from 2013 to 2033, with the case study of housing stock in Townsville Local Government Area (LGA). It integrates technologies in multi-criteria analysis and choice modelling, to better capture the sensitivity of different types of air conditioner and price tariff uptake across a landscape of heterogeneous consumers. Several variables were included in the modelling to characterise consumer preference of different air conditioners and tariffs: upfront cost (purchase price), annual cost (maintenance and running costs), household income, house age, visual appeal, convenience, comfort, familiarity and socio-economic rating. The model makes possible a highly granular geographical and demographic analysis, allowing uptake trends to be assessed for each ABS Statistical Area Level 1 (SA1) spatial unit of approximately 150 households, which Townsville LGA contains 431 residential SA1s. This provides a better understanding of the changes in peak demand across Ergon Energy electricity grid at scale of individual feeder. We show the base case along with sensitivity uptake to various electricity price scenarios.

To set up the diffusion model, ABS 2011 census data was used to formulate a typology of location (SA1) by building type by demographic variables. For the application to air conditioners, the following options were considered, no air conditioner, ducted, 1 split system, 2 split system, 3 split system, 1 box air conditioner, 2 box, 3 box. Townsville is currently a saturated market with 76% of households having three or more air-conditioners (Queensland Household Energy Survey 2011). For the base case scenario there was a significant shift from box air conditioners to split systems and ducted systems from 2013 to 2033. The main changes were about a 53% drop in houses with 3 box air conditioners, with these households mostly moving to either 2 split systems or ducted. When testing the sensitivity of various electricity price scenarios, it had minimal impact on market share of each air conditioner option at 2033, though the high electricity price scenario led to a modest reduction in ducted air conditioners.

For the application to time varying price tariffs, uptake of Tariff 33 increased to 81.7% by the end of 2033, up from 75% in 2013. The uptake of Tariff 12 and Tariff 33+12 was 0.64% and 2.19% respectively at 2033. Low uptake of the Tariff 12 scenarios was not surprising due to their minimal reduction in costs for detached housing and an increased annual electricity cost for semi-detached and apartment dwellings. When testing a scenario where the daily service fee for Tariff 12 was reduced to that of Tariff 11, this reduced the annual costs by $230/yr, and led to the uptake of Tariff 12 and Tariff 12+33 increasing to 0.82% and 2.81% respectively.

Keywords: *Choice Modelling, Multi Criteria Analysis*

Do More Signals Mean Higher Profits?

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Abstract: This paper examines the profitability of speculation trading by combining multiple technical indicators for entry requirements. The technical indicators considered in this paper include simple moving average and volume traded over different time horizons. Three different indicators were combined in thirty-two ways and the portfolios were followed for twelve years. Various methods of combining technical indicators will also be considered. The sample begins in January 2007 and it is chosen for purposes of analysing the impact of global financial crisis on trading. The performance of the different trading strategies will be evaluated by the annual risk-adjusted return of a portfolio. Trading costs are considered inconsequential in this case, given the proliferation of online brokerage companies, and will therefore be ignored.

The results contain evidence to support that forecast combination could be beneficial when applying to trading environment. More generally, this paper provides evidence to support that the advantage of forecast combination goes beyond improving mean-squared errors, it could also improve performance based on realistic objective functions.

Keywords: *Technical Trading, Combination, Stop-loss*

Extreme Movements of the Major Currencies traded in Australia

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Abstract: Following the event such as Global Financial Crisis (GFC) in 2008, financial institutions have suffered significant financial losses. Central banks have continuously bailed out financial distressed firms. However, such decisions from central banks cast doubt on the adequacy of current risk management strategy to reduce risk. Hence, the necessity of establishing robust risk evaluation techniques to manage losses during extreme events is critical. In particular, Value-at-Risk (VaR) has become an important measure of risk since the implementation of Basel II in 2008 and continues to become an important feature in Basel III. Even though the properties of VaR are well established, robust construction and forecast of VaR based on historical data remain unresolved. This is due to the difficulties in identifying the dynamics in asset's returns and it is extremely difficult to construct robust forecast without knowing the underlying process that governs the data. This paper proposes to estimate VaR by applying the extended version of the Hill's (1975) tail index estimator proposed in Berkes, et al. (2003). The extension incorporates potential time varying conditional variance and thus, provides a more robust method to estimate the tail index.

The paper will provide a concise overview on various tail index estimators and their extensions, including Mikosch and Starica (2000), Berkes, et al. (2003), Iglesias and Linton (2009) and Hill (2010). It also contains a brief overview on some of the popular conditional variance models, including the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model of Bollerslev (1986) and its asymmetric extension by Glosten, Jagannathan and Runkle (1993).

This paper will then forecast the VaR of exchange rate returns by estimating the tail index using daily exchange rate data on AUD with USD and GBP from January 1984 to December 2012. This approach is based on Iglesias and Linton (2009), Iglesias (2012) and Iglesias and Lagoa Varela (2012), which applied the tail index estimator proposed in Mikosch and Starica (2000) and Berkes, et al. (2003). The paper will also present a comparison of VaR between different conditional variance models suggested by Jorion (1996, 2007) to investigate the robustness of VaR estimates by tail index.

Keywords: *GARCH-type estimators, tail index, Value-at-Risk, exchange rates*

Logistic Models as Temporal Scaffoldings to Mimic Growth of Companies in the High Technology Sector

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Abstract: The fundamental postulate in corporate valuation is that the value of a corporation rests on its returns and the growth pattern of this stream. The returns on investment are operationalized as an estimated stream of net inward cash flow discounted into its "present value". This stream is summed into the infinite future. This is an expedient attempt to estimate the value of a corporation in light of the uncertainty embedded in the environment in which most corporations operate. Further, forecasting outcomes in turbulent market conditions are inherently unreliable. There are as many ways of modeling the future as there are practitioners and the performance of most of the recent financial forecasting models are at best of mixed success. Complex models are not necessarily better in forecasting than simpler ones. In practice, the important criteria for adopting a model include it being useful, understandable and robust. By "useful" here means that the model should be able to achieve its forecasting objective using relatively little resources, within an acceptable range of error, and be employed with reasonable confidence; by "understandable" here means the model must be sophisticated enough to do its job yet its behavior can be justified and explained without undue threat to its credibility; by being "robust" the model can be employed over a wide range of environmental conditions and parametrically fault tolerant.

Popular models employed in corporate forecasting sometimes contain both a short term component and a long term component. "Short term" components cater for that portion that can be forecast with relative confidence and the "long term" components are the portion that cannot be forecast, where assumptions were made with the best judgment. One such models used in valuation with varying degree of success is the Gordon Growth Model ("CGM") which combines the time value of money with a linear growth component such as represented in its simplest form as: $P = \frac{C_1}{k_e - g}$

where P is the value of the asset, C_1 is the cash received next year k_e generally cost of capital and g is the growth rate in the cash received going on forever. This form may be extended by tagging on various a priori scenarios incorporating various expectations such as "stable growth", "extraordinary growth" and "transitional periods". Here C_1 and k_e are well anchored in finance theory. It is the growth g that's the problem and the focus of this paper.

The gist of our argument is that imposing an a priori growth pattern that's not anchored in reality is not only intuitively unappealing but may prove financially ruinous. In this paper we examine a growth pattern that may help in ameliorating these weaknesses. This paper proposes the logistic family of S-curves as a means of superimposing lifecycle patterns upon corporations, a natural cycle of corporate growth. We provide empirical evidence of such behavioral growth patterns from a broad range of disciplines which were observed in nature and successfully modeled by using the logistic (S) curves. Using the S-curve, new corporate valuation models are proposed. Empirical predictions and valuations are examined using the cash-flows and dividend streams of selected corporations in the IT sector such as Microsoft, Apple Inc., Baidu Inc., Facebook, Google Inc., and TradeMe Ltd. respectively. We demonstrate that both the cash-flow and user numbers significantly fit their respective S-curves. The main conclusion of this paper is that S-curve has great potentials as a realistic forecasting tool in financial domains that involve evolution and growth. Given the right parameters, S-curves, as demonstrated in nature and in other disciplines, our paper demonstrates these logistic models can reasonably be used to model future growth/evolution in many financial and economic processes.

Keywords: *Logistic Models, S-Curve, Growth Models, evolutionary models*

The performance of hybrid ARIMA-GARCH modeling in forecasting gold price

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Abstract: Gold has been considered a safe return investment because of its characteristic to hedge against inflation. As a result, the models to forecast gold must reflect its structure and pattern. Gold prices follow a natural univariate time series data and one of the methods to forecast gold prices is Box-Jenkins, specifically the autoregressive integrated moving average (ARIMA) models. This is due to its statistical properties, accurate forecasting over a short period of time, ease of implementation and able to handle nonstationary data. Despite the fact that ARIMA is powerful and flexible in forecasting, however it is not able to handle the volatility and nonlinearity that are present in the data series. Previous studies showed that generalized autoregressive conditional heteroskedatic (GARCH) models are used in time series forecasting to handle volatility in the commodity data series including gold prices. Hence, this study investigate the performance of hybridization of potential univariate time series specifically ARIMA models with the superior volatility model, GARCH incorporates with the formula of Box-Cox transformation in analyzing and forecasting gold price. The Box-Cox transformation is used as the data transformation due to its power in normalizing data, stabilizing variance and reducing heteroskedasticity.

There is two-phase procedure in the proposed hybrid model of ARIMA and GARCH. In the first phase, the best of the ARIMA models is used to model the linear data of time series and the residual of this linear model will contain only the nonlinear data. In the second phase, the GARCH is used to model the nonlinear patterns of the residuals. This hybrid model which combines an ARIMA model with GARCH error components is applied to analyze the univariate series and to predict the values of approximation. In this procedure, the error term ε_t of the ARIMA model is said to follow a GARCH process of orders *r* and *s*.

The performance of the proposed hybrid model is analyzed by employing similar 40 daily gold price data series used by Asadi et al. (2012), Hadavandi et al. (2010), Khashei et al. (2009) and Khashei et al. (2008). From the plotting in-sample series, the gold price series does not vary in a fixed level which indicates that the series is nonstationary in both mean and variance, exhibits upward and nonseasonal trends which reflect the ARIMA models. The hybridization of ARIMA(1,1,1)-GARCH(0,2) revealed significant result at 1% significance level and satisfied the diagnostic checking including the heteroskedasticity test. The plotting of forecast and actual data exhibited the trend of forecast prices follows closely the actual data including for the simulation part of five days out-sample period. Consequently, the hybrid model of ARIMA(1,1,1)-GARCH(0,2) for the transformed data is given by

$$y_t^* = 0.274y_{t-1}^* + 0.726y_{t-2}^* + \varepsilon_t - 0.992\varepsilon_{t-1} \qquad , \varepsilon_t \sim iid\ N(0,1)$$
$$\sigma_t^2 = 1.16\times10^{-5} + 1.992\sigma_{t-1}^2 - 1.025\sigma_{t-2}^2$$

Empirical results indicate that the proposed hybrid model ARIMA-GARCH has improved the estimating and forecasting accuracy by fivefold compared to the previously selected forecasting method. The findings suggest that combination of ARIMA (powerful and flexibility) and GARCH (strength of models in handling volatility and risk in the data series) have potential to overcome the linear and data limitation in the ARIMA models. Thus, this hybridization of ARIMA-GARCH is a novel and promising approach in gold price modeling and forecasting.

Keywords: *ARIMA, GARCH, gold price forecasting, hybrid ARIMA-GARCH, Box-Cox transformation*

Optimal risk minimization of Australian energy and mining portfolios of stocks under multiple measures of risk

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Abstract: Australia's 2000's decade saw the sharpest rise in mining investments arising from developing Asian emerging economies' high demand for commodities like coal, iron ore, nickel, oil and gas which drove up prices to a historic level (Connolly & Orsmond, 2011). As of December 2012, 39 % and 9 % of the Australian Securities Exchange's stocks were of the mining (coal and uranium stocks are included in this category) and energy (e.g. oil, gas and renewable energy stocks) sectors respectively, and investors recently have been considering separate portfolio positions in energy and mining stocks (Jennings, 2010). Facts of these nature set the stage for the task of selecting an optimal portfolio of stock securities where the fundamental questions faced by every investor, individual or institutional, are: a) what is the optimal point in time to go long in the investment position?, b) what are the optimal amounts to invest in every asset of a portfolio? and, c) when is the optimal time to short the portfolio investment position? The focus of the present study is on b) within a one period ahead forecast scenario.

Understanding the price and volatility movements of stock securities taking as a basis of study their own dynamics and co-dynamics is a complex task that may be better addressed through a multilateral modelling approach. This paper, in this regard, departs from a single model application by fitting multiple risk measures to the optimization of four portfolios each consisting of 20 ASX's stocks from the gold, iron ore-nickel, uranium-coal and oil-gas sectors. The five risk measures compared are: the variance, mean absolute deviation (MAD), minimizing regret (Minimax), conditional value at risk (CVaR), and conditional drawdown at risk (CDaR), where the last two are threshold based measures. The risk measure parameters are input into mean-variance quadratic (QP) and differential evolution (DE) portfolio problem specifications.

Accurate estimations of the underlying interaction of stocks return series is a crucial element in portfolio allocation and portfolio risk management and frequentist traditional measures of dependence are rather inadequate. Here, with the objective of achieving more accuracy in the estimation of the dependence matrix, a Gaussian pair c-vine copula (PC), the regular graphical lasso (RL) and adaptive graphical lasso (AL) are fitted. Possible advantages from using these recently proposed and sophisticated techniques under model specifications where the covariance matrix is the measure of risk are indicated.

The main objectives of the present study are to calculate the optimal weights to be invested in every stock of the portfolios making use of linear and nonlinear model specifications and the risk measures suggested, analyse the weight allocation differences and seek portfolio optimization advantages from using pair vine copulas and the graphical lasso in the estimation of dependence. The present multimodal approach is, therefore, expected to be more robust and as a consequence, provide more complete information that could serve for improved decision making on portfolio selection, allocation and rebalancing. Research questions are answered based on the analysis of gold portfolio outcome values, only.

Findings indicate that CDaR is an important risk measure to be considered, along with other measures of risk when optimizing portfolios of stocks and no single measure of risk is suggested alone. The Gaussian pair c-vine copula through the use of one different parameter in the modelling of every pair of variables' joint distribution appears to be more sensitive in capturing data's distribution characteristics. The adaptive graphical lasso also appears to be more perceptive when grasping the signal of the underlying interaction of the stocks. Therefore, valuable information could be drawn and inferred from applying multiple risk measures and sophisticated statistical techniques for their estimation. The weight allocation from threshold risk measures such as CVar and DaR and Minimax clearly differs from the rest. The models identified stocks with high return relative to risk and vice versa. The originality of the present study lies on the sectors of application and its multi-model nature.

Keywords: *pair copulas, lasso, mean-variance quadratic, CVaR, CDaR, MAD, mining-energy stocks*

Understanding the Two-Way Relationship between the ASX and NZX Indexes: A Vector Threshold Autoregressive Modeling Approach

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Abstract: This paper focuses on the non-linear dynamic relationship between the stock markets in Australia and New Zealand. Specifically, we model the ASX 200 and NZX 50 equity indexes and the exchange rate between Australian and New Zealand dollars with a vector threshold autoregressive (VETAR) model.

In general, a VETAR model for a vector time-series $\mathbf{Z}_t = (z_{1t}, z_{2t}, \ldots, z_{nt})'$ can be expressed as follows:

$$\mathbf{Z}_t = \begin{cases} \omega_0^{(1)} + \sum_{j=1}^{p_1} \mathbf{\Phi}_j^{(1)} \mathbf{Z}_{t-j} + \mathbf{a}_t^{(1)}, & y_{t-d} \le r_1 \\ \omega_0^{(2)} + \sum_{j=1}^{p_2} \mathbf{\Phi}_j^{(2)} \mathbf{Z}_{t-j} + \mathbf{a}_t^{(2)}, & r_1 < y_{t-d} \le r_2 \\ \vdots & \vdots \\ \omega_0^{(k)} + \sum_{j=1}^{p_k} \mathbf{\Phi}_j^{(k)} \mathbf{Z}_{t-j} + \mathbf{a}_t^{(k)}, & r_{k-1} < y_{t-d} \end{cases},$$

where $-\infty < r_1 < \ldots < r_{k-1} < +\infty$. The model contains $k \ge 2$ regimes. In regime i, $\mathbf{Z}_t$ follows an order p_i vector autoregression, which has constant vector $\omega_0^{(i)}$ and autoregressive matrices $\mathbf{\Phi}_j^{(i)}$, $j = 1, \ldots, p_i$. The innovation vector in regime i is given by $\mathbf{a}_t^{(i)}$, which satisfies the equation $\mathbf{a}_t^{(i)} = \mathbf{\Sigma}_i^{1/2}\mathbf{e}_t$, where $\mathbf{\Sigma}_t^{1/2}$ is a symmetric positive definite matrix and $\{\mathbf{e}_t\}$ is a sequence of serially uncorrelated normal random vectors with zero mean vector and identity covariance matrix. The threshold random variable y_{t-d}, where d is the delay parameter, is assumed to be stationary and depends on the history of the time-series in question up to and including time $t-d$. The value of y_{t-d} relative to the fixed threshold parameters $r_1, \ldots, r_{k-1}$ determines which regime the system is currently in.

We estimate a VETAR model using stock index and exchange rate data from January 4, 2005 to June 20, 2013 inclusive. In particular, we set $\mathbf{Z_t} = (\Delta \ln(ASX_t), \Delta \ln(NZX_t), \Delta \ln(EX_t))'$, where Δ is the first difference operator, and ASX_t, NZX_t and EX_t are the time-t values of the ASX 200 index, NZX 50 index and the Australian dollar to New Zealand dollar exchange rate, respectively. In addition, we define the threshold random variable as $y_{t-d} = \Delta \ln(ASX_t) - (\Delta \ln(NZX_t) + \Delta \ln(EX_t))$. It was found that a three-regime VETAR model, with $d = 2$, $p_1 = 3$, $p_2 = 3$, $p_3 = 2$, $r_1 = -1.1842\%$ and $r_2 = 1.0569\%$ gives an optimal fit to the historical data.

The VETAR model has rich intuitions. The term $\Delta \ln(ASX_t)$ in the expression for y_{t-d} can be interpreted to mean the log return on an ASX 200 stock index fund, whereas the term $\Delta \ln(NZX_t) + \Delta \ln(EX_t)$ can be interpreted to mean the log return on an NZX 50 stock index fund, measured in Australian dollar. It is reasonable to expect y_{t-d} to fluctuate within a certain range, because after adjusting for currency differences, the returns on two (geographically) similar stock markets should not be highly different. Thus, an unusually small or large value of y_{t-d} is an indication of a market anomaly. The VETAR model captures such anomalies by permitting a change in regime when y_{t-d} falls below $r_1 = -1.1842\%$ or rises above $r_2 = 1.0569\%$.

On the basis the VETAR model, we propose a set of investment decision rules, which may be useful to hedge funds that are interested in the oceanic stock markets. The decision rules may also assist current and future retirees in Australia and New Zealand with the development of their retirement savings portfolios. By means of simulations, we demonstrate that using the VETAR model to make investment decisions may reduce the risk of an investment portfolio, in terms of risk measures such as Value-at-Risk.

Keywords: *Multivariate time-series, Non-linearity test, Risk management, Stochastic investment modeling, Value-at-Risk*

Time Series Properties of Liquidation Discount

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Abstract: This paper proposes an approach for quantifying liquidity risk. Urgent liquidation of a portfolio will entail a liquidation discount. This is the market impact discount in value yielded by the immediate sale of the portfolio relative to its in hand market value calculated from the prevailing market conditions.The proposed approach is to firstly construct the log liquidation discount rate using stock market data available from the order book. The behaviour of this empirical time series is modelled and subsequently used to predict future behaviour of the liquidity risk associated with the portfolio. This is achieved by constructing eight different sized portfolios, each corresponding to different numbers of shares from N stocks over two time periods (morning and afternoon). Each stock is to be liquidated on a daily basis. The bid side order book is used to price the immediate sale of a given stock at time t. The price differential between the bid value and market value of the stock is defined as the liquidation discount rate of the stock at time t. Replicating this process for N stocks produces a time series of portfolio liquidation discount rates. Specifically, there are total of eight time series which based on eight different scenarios, each consisting of a different number of shares for a given stock. These scenarios are represented by α which denotes differing proportions of all shares on issue for a given stock. A log transform is applied to the series and these are further segmented into two time periods to investigate liquidity behaviour over time.

This paper proposes to model the time series properties of the log liquidation discount rate using the Autoregressive Fractional Integrated Moving Average (ARFIMA) - Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model. The mean component of the series is modelled using the ARFIMA(r, d, s) model and contains both ARMA(r, 0, s) and ARIMA(r, 1, s) as special cases ($d = 0$ and $d = 1$ respectively). The GARCH(p, q) model is used to model the variance component. A number of models are tested under varying lag structures i.e. different values of p and q. Model performance is based on a model's ability to forecast future values of log liquidation discount rate. The forecast accuracy is measured using the mean square error (MSE). Optimal models resulting from differing values of α over two time periods are identified. The results indicate that the ARFIMA(p, d, q) - GARCH(p, q) model consistently produces the most accurate forecasts over both time periods. For practical purposes a simpler model (in terms of lag structure) is proposed. This model offers a more intuitive interpretation with only a marginal loss in performance. The parameter estimates pertaining to each model are averaged over all values of α for each time period. This produces a two final models each corresponding to a time period. Using these models one can forecast (over n horizons) the variance of the log liquidation discount rate. This forecast is interpreted as the future liquidity risk associated with the portfolio. The empirical results suggest that the variance converges to its long run value at a faster rate in the morning compared to the afternoon.

Keywords: *Liquidity risk, fractional differencing, GARCH, time of day effect*

The Impact of Chinese Tourists on Volatility Size Effects and Stock Market Performance in Taiwan

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Abstract: This paper investigates the volatility size effects for firm performance in the Taiwan tourism industry, especially the impacts arising from the tourism policy reform that allowed mainland Chinese tourists to travel to Taiwan. Four conditional univariate GARCH models are used to estimate the volatility in the stock indexes for large and small firms in Taiwan. Daily data from 30 November 2001 to 27 February 2013 are used, which covers the period of Cross-Straits tension between China and Taiwan. The full sample period can be divided into two subsamples, namely prior to and after the policy reform that encouraged Chinese tourists to Taiwan. The empirical findings confirm that there have been important changes in the volatility size effects for firm performance, regardless of firm size and estimation period. Furthermore, the risk premium reveals insignificant estimates in both time periods, while asymmetric effects are found to exist only for large firms after the policy reform. The empirical findings should be useful for financial managers and policy analysts as it provides insight into the magnitude of the volatility size effects for firm performance, how it can vary with firm size, the impacts arising from the industry policy reform, and how firm size is related to financial risk management strategy.

Keywords: *Tourism, firm size, conditional volatility models, volatility size effects, asymmetry, tourism policy reform*

Modelling asset return using multivariate asymmetric mixture models with applications to estimation of Value-at-Risk

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Abstract: Value-at-Risk (VaR) is a widely used statistical measure in financial risk management for quantifying the level of risk associated with a specific investment portfolio. It is well-known that historical return data exhibit non-normal features, such as heavy tails and skewness. Current analytical (parameteric) calculation of VaR typically assumes the distribution of the portfolio return to be a normal or log-normal distribution, which results in underestimation and overestimation of the VaR at high and low confidence levels, respectively, when a normal distribution is assumed.

This study develops a promising approach in modelling asset returns by fitting multivariate mixture models with asymmetric component densities, in particular, members of the skew-symmetric family and other non-elliptically contoured distributions. We focus on component densities with four or more parameters, including the multivariate skew t (MST) distribution, the multivariate normal-inverse-Gaussian (MNIG) distribution, and the multivariate generalized hyperbolic distribution (MGH) distribution. These distributions have proven to be effective in capturing heterogeneous data with asymmetric and heavy tail behaviour, and can flexibly adapt to a variety of distributional shapes. The fitting of these mixture models can be carried out via the Expectation–Maximization (EM) algorithm.

This approach has improved the accuracy of VaR estimation, and an example is demonstrated on a portfolio of three Australian stock returns. The asymmetric mixture models were fitted to the monthly returns of the shares Flight Centre Limited (FLT), Westpac Banking Corporation (WBC) and Australia and New Zealand Banking Corporation Group Limited (ANZ) for the period January 2000 to mid 2013. The VaR estimates predicted by the asymmetric mixture models for a range of significance levels of interest compare favourably to traditional methods based on symmetric models, with significant improvements observed in the accuracy of the estimates. Moreover, it is observed that models with relatively restrictive component densities (such as the normal mixtures, skew normal mixtures and shifted asymmetric Laplace mixtures) require a mixture of two components in order to accommodate the skewness and heavy-tails in the data, whereas the more flexible distributions can adequately capture the distributional shape of data with only a single component.

Keywords: *mixture model, skew distributions, skew t-mixture model, generalized hyperbolic distribution, EM algorithm, Value-at-Risk*

Sustainable fisheries and conservation management with environmental derivatives

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Abstract: Environmental management agencies often try to keep natural assets within specific limits, and when they fail, recovery efforts must be implemented. Unfortunately, recovery efforts can be expensive. Environmental derivatives offer a solution. An environmental derivative is a contract where one party assumes the financial risk of recovery efforts in exchange for an upfront payment. The biggest challenge to using environmental derivatives in this manner is determining the payment price. We show payment prices for two natural assets in Australia (fish stocks) calculated using population dynamics forecast models. Prices reflect the risk associated with the contractual payout. Depending on how the asset is managed, a 20-year American-type derivative contract for a healthy school whiting fish stock in southeast Australia ranges between $0.01 and $32, for each $100 promised in recovery pay-off, if it is needed. The price of a similar contract for the more depleted tiger flathead fish stock is between $0.71 and $42. The results demonstrate that environmental derivatives can 1. finance recovery efforts when they are needed; 2. provide incentive to formally adopt and compare rules-based management strategies; and 3. signal the underlying health of natural assets through the transparent derivative price. This work represents an essential first step towards developing a market for risk management of natural assets. Such markets would require independent regulatory institutions, with a scientific directive to address key uncertainties affecting the asset risk and thus market price.

Keywords: *Bio-economic modeling, conservation finance, environmental derivatives, environmental risk analysis, management strategy evaluation, recovery costs, restoration*

Modelling a Human Well-Being Indicator

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Abstract: This paper analyses the Happy Planet Index (HPI) as a new human well-being indicator, and its deterministic relationships with a range of macroeconomic, social, and political factors. In addition, this paper identifies any lead-lag relationships between the variables studied. This study employs a panel data comprising 25 OECD countries over a period of 16 years from 1994 to 2009. The deterministic relationships are modelled with Pooled Ordinary Least Square (POLS) regressions, and any lead-lag relationship is identified by applying Granger causality tests to the panel dataset. This study finds that conventional macroeconomic indicators such as GDP per capita, unemployment rate, and inflation rate are statistically significant in explaining HPI, though the relationship is negative. Overall, the selected variables are successful in explaining HPI. The study also finds significant causal relationships between HPI and some of the variables. This paper contributes to the literature by studying a relatively new human well-being variable, and by using a panel dataset which significantly increases the power of the tests.

Keywords: *Well-being, determinants, causality, economy, sustainability*

Dynamic Bargaining and CDM Low Hanging Fruits with Endogenous Total Emission Abatement Target

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Abstract: A three-stage dynamic model of climate change negotiation featuring developed and developing country is constructed in order to capture Copenhagen COP of UNFCCC and subsequent developments. In stage 1 (Copenhagen), countries negotiate a long-run (total) emission abatement target $T(=q+Q+Q^{'})$, leaving specific terms of agreement undecided. In stage 2 (CDM), they negotiate emission reduction obligation q that only the developed country bears. In stage 3 (post-CDM), both countries bear abatement obligation and negotiate their respective abatement obligations $Q^{'},Q$. As they engage in stage 1 and 2 negotiations, they cannon commit themselves for period 2 abatement, which leads to the well-known problem of incomplete contract. We associate this situation with so-called CDM Low Hanging Fruits problem. We examine the gain and loss on the part of the developing country to see if their low-hanging fruits are indeed shortchanged.

Keywords: *Climate Change, Kyoto Mechanisms*

Public Good Provision: Lindahl Tax, Income Tax, Commodity Tax, and Poll Tax, A Simulation

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Abstract: There are two traditions in the argument on taxation. On the one hand, the argument on taxation is constructed in such a way that which taxation is desirable in order to impose a tax, income tax, commodity tax or poll tax, without paying any attention on why the tax is necessary. In the partial equilibrium framework, the lump-sum tax, such as poll tax, is regarded as the best. On the other hand, it is also a tradition to assert that government imposes a tax in order to provide public goods. This paper integrates the above two traditions by constructing a primitive general equilibrium (GE) model which incorporates a public good, asking which taxation is desirable in order to impose tax, income tax, commodity tax, or poll tax to optimally provide the public good. Formally, in Part I, we start with utilizing the Lindahl mechanism to compute a Pareto-optimal public good level under a specification of the parameters on production and utility functions. The burden-sharing in this Lindahl mechanism may be regarded as a tax on the society members, while utilizing pseudo-market mechanism. We call it Lindahl tax. Next, we compute the rate of income tax in order to sustain the optimal public good level, and compare the Lindahl tax and income tax. We proceed to the computation of the rate of (proportional) commodity tax in order to sustain the optimal public good level, and compare the Lindahl tax, income tax and commodity tax. Finally we proceed to the comparison between the Lindahl tax, income tax, commodity tax and poll tax under the specification of the model. In Part II, selecting the parameters randomly, we examine the robustness of the conclusion in Part I. Production functions are assumed as the Cobb-Douglass type while the utility function as the CES type with k the substitution parameter. It was shown for a specified case that when $0<k<1$, there exists no general equilibrium for the poll tax case, while the income tax (and proportional commodity tax) is more desirable than the Lindahl tax not only from the fairness viewpoint but also from the utilitarian efficiency viewpoint under some specification of parameters. It was also shown for another specified case that even when $0<k<1$, there exists general equilibrium for the poll tax case, and the income tax and the commodity tax is more desirable than the Lindahl tax, while the comparison between the poll taxation and other taxations are impossible from the above mentioned two viewpoints. Finally, specifying parameters on production and utility functions and initial endowments randomly, this paper showed that when $0<k<1$, the income tax (and proportional commodity tax) is more desirable than the Lindahl tax from the fairness and efficiency viewpoints with high possibility of non-existence for poll tax general equilibrium. However, when $k<0$, specifying parameters on production and utility functions and initial endowments randomly, this paper showed that the Lindahl tax is more desirable than the income tax (and proportional commodity tax) from the fairness and efficiency viewpoints with high possibility of existence for poll tax although the comparison between the poll tax and other taxes are impossible from the two viewpoints. Thus, this paper showed that the comparison completely depends on the substitution parameter of the CES utility function.

Keywords: *General equilibrium, public good, Lindahl mechanism, income tax, commodity tax, poll tax*

Incentive Aspects of the Standardization of baseline in the Project based mechanisms in the international environmental cooperation

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Abstract: CDM was the major source of supply of emission traded at EU-ETC, although there were several criticisms against it. We examine a possible standardization of baseline setting method as discussed in the CDM reform at KP of UNFCCC and its CDM-EB in order to simplify the procedure and mitigate the costs born by the applicant, which was blamed for one major source of eclipse of CDM projects in the LDC.. Especially we tried to examine the role of transaction costs and self-selection under such baseline setting method. Combining several assumptions, we show that various problems could come out, and we tend to favor resolving the issue of transaction costs by itself rather than resolution via the standardization of the baseline setting methods.

First, we set out a simple model with a fixed output level to introduce baseline setting corresponding to the current practice with perfect information, (which of course is an idealization). Compared to this is a standardized baseline setting method where at the certain level, baseline emission level of GHG (in terms of emission factor) . We take the case of greenfield project due to increased demand in an industry, so that even without a registration as a CDM project and hence no credits revenue some project would take place with possibly more emissions.

Then introducing uncertainty into some parameters, we examine the set of potential projects attracted to CDM under each baseline setting method with transaction costs explicitly accounted for as a component of fixed costs. As an immediate and obvious conclusion, due to the alleviation of the transaction costs, smaller projects would be induced to apply for the CDM. However, because of our simplified setup where true baseline level is not accompanied with an increased production cost, no over-crediting takes place.

Next we consider a particular assumption due to Fischer that emission level after the project and the true baseline level are proportional. Under this assumption, it is possible that quite different types of projects are induced to apply for CDM, and therefore there is a possibility of over-crediting. Introducing the possibility of scale parameter and the parameter representing a true baseline emission level, we observe that several possibilities could coexist.

Finally we account for the proposal made by CDM-EB with some warning based on the observations made above. Then we conclude that even though the CDM itself may be doomed to fade out, the issue of correct measurement of emission reduction , and to that effect any activity for the public good, is the major issue in the international negotiation together with several new mechanisms proposed, and so the results obtained in this exercise here could be of certain values for the future argument in the international environmental policy, especially of the economic mehanisms.

Keywords: *CDM, baseline-credit*

Does the Definition of Retirement Matter in Estimating the Effects of Retirement on Cognitive Functioning?

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Abstract: The purpose of this paper is to examine the causal impact of retirement on the cognitive functioning of male elderly workers using data from three waves of the National Survey of Japanese Elderly (NSJE). We examine how the definition of retirement affects the findings of Kajitani et al. (2013) where they examined the effects of the longest tenure job (career job) on cognitive functioning. Here, we use the status of retirement rather than the duration of retirement. The two step estimator we use takes account of the potential endogeneity of the status of retirement, using the age at which individuals are eligible to start receiving pension benefits and whether their career job was self-employment as instruments. Our empirical evidence suggests that the requirements in a person's career job have statistically significant impacts on the cognitive functioning after retirement. Kajitani et al.'s (2013) findings are found to be robust irrespective of the definition of retirement.

Keywords: *Retirement, Cognitive Functioning, Occupation*

Scale effect in blockbuster research and development: The differences between production in Japanese Firms and in US/EU Firms

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Abstract: The purpose of this study is to empirically analyze the differences between blockbuster (big sales new drugs) production in Japanese firms and in US/EU firms. Many previous studies used the NCEs (New Chemical Entities) or patents as a measure of the performance of pharmaceutical R&D. But most of the profit of the pharmaceutical companies is gained by small number of new drugs with big sales, called blockbusters. Thus, we focus on blockbuster research and development in this study.

The pharmaceutical R&D can be divided into the research and the development processes. The research process is the process to seek a NCE candidate protected by the patent. On the other hand, the development process makes up one of the NCEs into a new drug. For this reason, we analyze not only the differences in research process but also the differences in development process.

The estimation results for Japanese firms are summarized as follows: The research process shows decreasing returns to R&D investment scale, but the development process shows increasing returns. On the other hand, the estimation results for US/EU firms, larger than Japanese firms in their operating scale, are summarized as follows: The research process shows decreasing returns to R&D investment scale, but the development process shows constant returns. From these estimation results, we find important differences between blockbuster production in Japanese firms and in US/EU firms. US/EU firms are lager than Japanese firms, but the blockbuster production in development process of US/EU firms is low. While the blockbuster production in research process of US/EU firms is similar to Japanese firms.

Keywords: *blockbuster R&D, Scale effect, Japanese Firms, US/EU Firms*

Evaluation of the 2006 revision of the medical payment system in Japan by a new estimator of the power transformation model – An analysis of the length of the hospital stay for cataract operations

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Abstract: Since Japanese medical expenses have been increasing rapidly with aging of the population, shortening the average length of stay (ALOS) by reducing long-term hospitalizations has become an important political issue in Japan. A new inclusive payment system based on the Diagnosis Procedure Combination (DPC) was introduced in 82 special functioning hospitals (i.e., university hospitals, the National Cancer Center and the National Cardiovascular Center) in April 2003 in Japan. The DPC Evaluation Division of the Central Social Insurance Medical Council (2010) started to call the new inclusive payment system based on the DPC the DPC/PDPS (per diem payment system), and we use this term and refer to hospitals participating in the DPC/PDPS as DPC hospitals throughout this paper. Since April 2004, the DPC/PDPS has been gradually extended to general hospitals, and it has been revised every two years after that. As of July 2010, a total of 1,391 hospitals, about 18% of the 7,714 general hospitals in Japan, had joined the DPC system. These DPC hospitals have 458,707 beds, which represents about a half of the total number of beds (909,337 beds) in all general hospitals. The introduction of the DPC/PDPS was one of the largest and most important revisions of the payment system since the Second World War. To ensure the effective use of medical resources, it is absolutely necessary to thoroughly analyze the DPC/PDPS. However, sufficient evaluations of the system have not yet been done. Empirical studies of the LOS and medical payments using econometric models are necessary to evaluate the system correctly. A simple comparison of the ALOS by hospital is not sufficient; differences in types of disease must be considered, and the individual characteristics of patients and types of treatment must also be considered for the same disease.

The Box-Cox (1964) transformation model (hereafter, the BC model) is widely used to examine various problems in survival analysis, such as the LOS. However, since the error terms cannot have a normal distribution except in the case where the transformation parameter is zero, the likelihood function under the normality assumption (hereafter, the BC likelihood function) is misspecified and the maximum likelihood estimator (hereafter, the BC MLE) cannot be consistent. Alternative versions of the BC model have been proposed by various authors. However, because the simplicity of the model is lost with these versions (Showalter, 1994), these alternatives have not been widely used.

In this paper, we first propose a new estimator of the power transformation model (the Box-Cox transformation model excluding the case in which the transformation parameter is zero). The estimator is a modification of the BC MLE and proved to be consistent. We then evaluate the effects of the 2006 Revision of the DPC/PDPS on the LOS and the medical payment for cataract operations（DPC category code: 020110）. The number of cataract patients in Japan has been increasing rapidly with the aging of the population. According to a survey conducted by the Ministry of Health, Labour and Welfare (2008), nearly 800,000 cataract operations are performed annually and nearly 2.5 billion yen are spent for cataract operations annually . In the case of cataract operations, a major change was made concerning the DPC classifications, the three periods, and inclusive payments determined by DPC/PDPS in the 2006 Revision. To evaluate the revision, we analyzed the data collected from 20 DPC hospitals before and after the revision. The number of patients in the data set is 4,394.

Keywords: *Diagnosis Procedure Combination (DPC), inclusive payment system, cataract, length of stay (LOS), Box-Cox transformation model, power transformation model*

Robust estimation based on the first- and third-moment restrictions of the power transformation model

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Abstract: The Box-Cox (1964) transformation model (hereafter called the BC model) is widely used in various fields of econometrics and statistics. However, since the error terms cannot be normal except in cases in which the transformation parameter is zero, the likelihood function under the normality assumption (hereafter the BC likelihood function) is misspecified and the maximum likelihood estimator (hereafter the BC MLE) cannot be consistent. Alternative distributions of the error terms and transformations for the BC model have been proposed by various authors. However, these alternative estimators are not inconsistent if the distributions of the error terms are misspecified. Foster, Tain, and Wei (2001) and Nawata and Kawabuchi (2013) proposed semiparametric estimators. However, their estimators are not consistent under heteroscedasticity.

Powell (1996) proposed a semiparametric estimator based on the moment restriction. Although Powell's estimator is consistent under heteroscedasticity, the problems of the estimator are: (i) to identify the transformation parameter, λ, we need to introduce one or more instrumental variables, w_t, which satisfy $E(w_t \cdot u_t)=0$ and are not included in x_t, and the result of the estimation changes depending on the selection of instrumental variables, (ii) as pointed out by Khazzoom (1989), when all observations are $y_t<1$, the objective function is always minimized at $\lambda=\infty$ (or at $\lambda=-\infty$ if $y_t>1$ for all observations), so that a rather arbitrary rescaling of y_t is necessary, and (iii) its finite-sample properties are not good and it often performs poorly, as shown in the Monte Carlo experiments.

Here I propose a new robust estimator of the power transformation model (the Box-Cox transformation model excluding the cases in which the transformation parameter is zero) given by

$$z_t = x_t'\beta + u_t, \quad z_t = y_t^{\lambda}, \qquad y_t \ge 0, \ t = 1,2,\dots,T.$$

The estimator is based on only the first- and third-moment restrictions of the error terms and does not require the assumption of a specific distribution. The estimator is a root of the equations;

$$\sum_t (z_t - x_t\beta)^3 = 0, \ \text{and} \quad \sum_t x_t(z_t - x_t'\beta) = 0.$$

The estimator is consistent if the first- and third-moments of the error terms are zero; that is, it is consistent even under heteroscedasticity. Moreover, it can be easily calculated by the least-squares and scanning methods. The results of the Monte Carlo experiments show the superiority of the proposed estimator over the BC MLE and Powell's estimator.

Keywords: *Box-Cox transformation, power transformation, heteroscedasticity, robust estimator, moment restriction*

A dynamic credit ratings model

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Abstract: The Global Financial Crisis (GFC) provided overwhelming evidence of the problems caused by inadequate credit ratings. Losses and problem loans experienced by banks over this period were staggering. Yet many of the securitized sub-prime parcels which were widely seen as an underlying cause of the GFC, as well as corporate obligors who experienced severe difficulties during the GFC, retained extremely strong external credit ratings. They may have had low perceived risk at the time of rating, but as circumstances changed, the ratings stayed static and became far removed from the underlying risk. A key problem is that the external credit ratings do not fluctuate with changing economic circumstances. Whilst there are models which measure changing default risk, they are not linked to credit ratings and it is often the rating itself, not the underlying risk that drives behavior, such as the purchase of securitized parcels, the pricing of credit risk, and the allocation of capital for credit risk, which under the Basel standardized model for corporates is based on the rating itself. This problem is exacerbated by the fact that these ratings carry descriptors such as "extremely strong capacity". This descriptor may no longer be appropriate for the rated company if the market turns dramatically, yet the rating and descriptor remain unchanged.

To overcome this problem, this paper shows how an innovative fluctuating credit ratings model can be generated by linking the Merton structural credit model to a credit ratings framework. The Merton model measures fluctuations in daily asset values and, using a combination of these fluctuating asset values and the capital structure of a company, it measures Distance to Default (DD) and the Probability of Default (PD) associated with each DD. Under the Merton structural model, default occurs when the firm's debt exceeds asset values. Thus as fluctuations in asset values become more volatile, DD also becomes more volatile and PD increases. External raters such as Moody's provide PD's associated with each rating. Thus by using the Merton model, we are able to generate PDs which fluctuate over time and link these PD's to credit ratings. Therefore, as our PD's fluctuate, so do the credit ratings.

To illustrate our approach, we apply this model to a French motor vehicle company (Renault) which experienced severe distress during the GFC. We compare the Moody's rating changes that took place for Renault over the 2006 – 2009 period, which captures the events leading up to and during the GFC. Over this period, only three Moody's external ratings changes took place and throughout this period, Renault stayed in the Moody's 'moderate' risk band. Based on this, an investor would likely assume the company was in reasonable financial health, and a bank would not be required to change its capital allocation for this company if it was a borrower. Yet during this period, the company experienced such severe financial problems that it had to be bailed out by the French Government. Our model, on the other hand, recognizes these stresses far quicker, starting with rating downgrades for Renault from August 2007 and moving downwards through several risk bands, from 'moderate' to 'substantial' to 'high' and then to 'very high' credit risk. This downward spiral is far more in keeping with the actual problems experienced by Renault than the static 'moderate' risk tag would indicate. We thus find that the new model responds extremely rapidly to changing economic circumstances to produce ratings which can far more accurately depict the underlying credit risk of a corporate obligor in these times than prevailing external rating methods.

The new ratings can benefit bond investors and banks through improved knowledge of the underlying credit risk of bonds and of corporate borrowers. As capital adequacy can also be linked to credit ratings, an improved rating model can assist banks and regulators to better measure required capital adequacy to protect against economic downturns.

Keywords: *Credit risk, Credit ratings, Fluctuating default risk*

Primary sector volatility and default risk in Indonesia

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Abstract: The Indonesian market is a critical market to the South East Asian region, being that region's largest economy. The primary sectors of the Indonesian economy, incorporating Agriculture and Mining, are of critical importance to the country, representing approximately one quarter of GDP and providing nearly 40% of the nation's employment. Mining and Agriculture stock returns significantly outperformed the Indonesian Stock Exchange (IDX) composite index in the five years leading up to Global Financial Crisis (GFC), and experienced savage falls during the GFC. Against this background, we examine the market and credit risk of these sectors during the pre-GFC, GFC and post-GFC periods.

Market risk is measured using Value at Risk (VaR) and Conditional Value at Risk (CVaR). VaR is a popular metric which measures potential losses over a specific time period, up to a selected threshold. A key downside of this metric is that it says nothing of the extreme risk beyond VaR, which is a major limitation for this study, given the extreme volatility experienced by the primary sectors in Indonesia over the studied period. We therefore also use CVaR, which measures the extreme risk beyond VaR.

For credit risk, we use the Merton-KMV Distance to Default (DD) metric, as well as our own Conditional DD (CDD) metric to measure extreme default risk. The key advantage that the Merton-KMV model has over other credit models, it that it incorporates fluctuating asset values. This makes it more responsive to changes in market conditions than most other credit models which remain static between rating periods. The importance of fluctuating asset values in measuring credit risk has been raised by the Bank of England (2008), who make makes the point that not only do asset values fall in times of uncertainty, but rising probabilities of default make it more likely that assets will have to be liquidated at market values. Similar to VaR, the Merton-KMV model has deficiencies in that it uses the standard deviation of asset value fluctuations, which tends to smooth the volatility and does not capture tail risk over that period. Our CDD model is able to measure risk at the most extreme times of the economic cycle, which is precisely when firms are most likely to fail, and when banks are most likely to experience high credit losses.

We find that market risk for the primary industries is significantly higher than the broader market, and that there is a relatively higher difference between VaR and CVaR, indicating a higher tail risk. Mining, in particular has a higher market risk than other Indonesian sectors. Interestingly, this is not the case with credit risk, where the risk for Agriculture is lower than the overall market, and the risk for Mining is not significantly different to the overall market. This is because the leverage of a firm is a key component of the Merton-KMV model and we find the leverage for the Agriculture and Mining industries to be far more conservative than the broader market. This means that these primary sectors are able to withstand relatively higher levels of asset volatility.

These findings can benefit both lenders and investors when considering the inclusion of these sectors in their investment or loan portfolio mix.

Keywords: *Agriculture, mining, value at risk, distance to default*

Dependence estimation and controlled CVaR portfolio optimization of a highly kurtotic Australian mining sample of stocks

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Abstract: The drivers of mining stock prices are known to be several. Sharp spikes on the stocks return distribution have been linked to the presence of unusually high volatility signifying the presence of high levels of kurtosis. The accurate measurement of the stocks' underlying co-movements for more accurate CVaR portfolio optimization requires, therefore, the utilization of sophisticated and specific-specialized techniques which could adequately capture and model these characteristics. Here this issue is addressed by applying statistical-graphical models for dependence estimation. Twenty mining stocks, out of the 801 listed in the ASX as of December 2012, have been selected for the analysis under the criteria of satisfying the eight years trading period sought, having very weak or no autocorrelation of residuals and displaying the highest kurtosis. Models' estimations of dependence are compared and inserted into a differential evolution algorithm for non-convex global optimization in order to conduct risk controlled CVaR portfolio optimization (Ardia, Boudt, Carl, Mullen & Peterson, 2011) and be able to identify the one yielding the highest portfolio return. The findings are of relevance in portfolio allocation and portfolio risk management.

Energy and mining stock markets are subjected to numerous price drivers holding complex relationships. The dynamics of production and consumption based on seasonality features, transportation and storage, weather conditions, commodity price fluctuations, currency changes, market confidence and expectations, trading speculations and the domestic and international states of the economy impact mining stock prices in particular and unobvious ways reflected in high volatility with sudden spikes in the stock's return distribution (Pilipovic, 1998). The generation of accurate measurements of the dependence matrix of mining stock's return series is therefore both, a non-trivial task due to the hard to decipher characteristics present in return series suffering from high levels of kurtosis (Carvalho, Lopes & Aguilar, 2010) and, a crucial element in portfolio optimization and portfolio risk management.

The use of graphical techniques in this study is justified on the basis of their utility and suitableness. Graphical models such as pair c-vine copulas, the graphical lasso and adaptive graphical lasso provide, for instance, the visualization and flexibility to represent a problem in a more simplified and dissected form (Lauritzen, 1996). Graphs also appear to be naturally adequate to express the interaction of variables and thus facilitate the analysis of their dependency. The models of dependence estimation and CVaR portfolio optimization, on the other hand, are desirable due to mathematical and statistical framework they provide which may lead to satisfactory results and, their apparent ability to overcome the flaws (i.e. standardized model application to all joint distributions, restrictive and deterministic linear and monotonic modelling functions as in the Pearson and Spearman) traditional measures display when dealing with highly kurtotic data, joint distributions with stronger dependence in the tails and controlled risk non-convex portfolio optimization problems. Findings indicate that the highest portfolio returns are generated by inserting the covariance output matrix from the student-t copula into the differential optimization algorithm and, the student-t copula fitting with separate modelling of the marginal distributions appears to be the most desirable modelling choice. The portfolio return by the adaptive graphical lasso is lower than that of the student-t and is followed by the Gaussian pair c-vine copula. The regular graphical lasso produced the lowest portfolio return and the covariance matrix values were higher for models producing the highest portfolio returns implying that the models generating the lowest portfolio returns underestimated the dependence of the assets. The implications of the findings suggest that specific modelling of each marginal distribution, as compared to modelling based on a Gaussian framework, may lead to an edge in the estimations due to the distribution differences encountered on each marginal. Furthermore, the ability of the model to capture dependence in the tails, as it is the case of the student-t copula, does provide a modelling advantage too. This paper appears to be the first one in, comparing the portfolio performance of the models of dependence estimation in the context of controlled CVaR, applying the models treated to a highly kurtotic mining sample of stocks from the Australian market and modelling separately the distribution of the marginals when fitting the student-t copula.

Keywords: *Dependence structure, copula, CVaR, differential evolution, mining stocks.*

Intraday Volatility Forecast in Australian Equity Market

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Abstract: On the afternoon of May 6, 2010 Dow Jones Industrial Average (DJIA) plunged about 1000 points (about 9%) in a matter of minutes before rebounding almost as quickly. This was the biggest one day point decline on an intraday basis in the DJIA's history. An almost similar dramatic change in intraday volatility was observed on April 4, 2000 when DJIA dropped by 4.8%. These historical events present very compelling argument for the need of robust econometrics models which can forecast intraday asset volatility. There are numerous models available in the finance literature to model financial asset volatility. Various Autoregressive Conditional Heteroskedastic (ARCH) time series models are widely used for modelling daily (end of day) volatility of the financial assets. The family of basic GARCH models work well for modelling daily volatility but they are proven to be not as efficient for intraday volatility. The last two decades has seen some research augmenting the GARCH family of models to forecast intraday volatility, the Multiplicative Component GARCH (MCGARCH) model of Engle & Sokalska (2012) is the most recent of them. MCGARCH models the conditional variance as the multiplicative product of daily, diurnal, and stochastic intraday volatility of the financial asset. In this paper we use MCGARCH model to forecast intraday volatility of Australia's S&P/ASX-50 stock market, we also use the model to forecast the intraday Value at Risk. As the model requires a daily volatility component, we test a GARCH based estimate and a Realized Variance based estimate of daily volatility component.

Keywords: *Intraday returns, volatility, value at risk, ARCH, realized variance*

Interest rate sensitivities of externally and internally managed Australian REITs

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Abstract: Real Estate Investment Trusts (REITs) in Australia experienced tremendous growth and investor interest following the crash of unlisted property funds in the 1990s. Since 2001, management structures have shifted from external property management to an internally advised model. The sector's returns had been notably rewarding up till the Global Financial Crisis but rising costs of debt and years of aggressive borrowing to fund expansions have eroded the values of REITs. Externally managed trusts had relatively higher levels of debt than their internally managed counterparts thus increasing the sensitivities to interest rate risks. Yet internally managed REITs engage in a wider set of operating activities which compound exposures to market and financial risks.

Using panel regressions, this paper aims to examine the joint impact of financial leverage and management structure on REIT returns in terms of their sensitivities towards stock market returns and changes to yields of 10-year bonds and 90-day bank accepted bills. We utilise a sample period of monthly data from January 1980 to March 2013. Panel quantile regressions are also employed to analyse how sensitivities to market risks, short and long-term interest rate risks vary at different parts of an economic cycle.

Our study finds that REITs are positively related to the stock market and the effect is greater for REITs with greater financial leverage as well as stapled trusts. REITs are only negatively affected by short-term interest rates at the lowest 5 per cent quantile of returns. Long-term interest rates have an inverse effect on REITs only at the upper 75 and 95 per cent quantiles. We consider the possibilities that rental yields and inflationary expectations may offset the influences of financing costs. Internal management appears to compound market and interest rate risks. These have implications on investors looking to select REITs as substitutes of direct property investments.

Keywords: *REITs, financial leverage, interest rate risk, panel quantile regressions*

Identifying Efficient Exchange Rate Dynamics from Noisy Data

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Abstract: This paper proposes a new methodology to estimate a simple spot and forward exchange rates model. The method is inspired by the recent development in Independent Component Analysis (ICA) and it allows the identification and estimation of efficient exchange rate (exchange rate when market is efficient) and external market influences (market noise).

Consider the linear equation $\mathbf{y}_t = A\mathbf{x}_t$, where $\mathbf{y}_t$ and $\mathbf{x}_t$ are $k \times 1$ vectors of observable and unobservable random variables, respectively, and A is a $k \times k$ matrix. Under the assumption that each element in $\mathbf{x}_t$ is independent to each other and $\mathbf{x}_t$ consists of no more than one normal variate, then Independent Component Analysis (ICA) provides a convenient framework to recover the mixing matrix A, subject to scaling and permutation, by utilising the independence and non-normality nature of $\mathbf{x}_t$. Subsequently, it is also possible to recover $\mathbf{x}_t$ based on the observations of $\mathbf{y}_t$, subject to scaling and permutation.

Let $\mathbf{y}_t$ denotes a $k \times 1$ vector of co-integrated $I(1)$ variables, then following the Granger's Representation Theorem and the Phillips' Triangular Representation, there exists a $k \times k$ matrix, A, and a $k \times 1$ vector, $\mathbf{x}_t$, such that $\mathbf{y}_t = A\mathbf{x}_t$. Moreover, there are exactly r $I(0)$ elements and $k - r$ $I(1)$ elements in $\mathbf{x}_t$. This paper shows that, under the same assumptions of ICA, it is possible to estimate A, and recover the unobserved random variables, $\mathbf{x}_t$, based solely on the observations of $\mathbf{y}_t$. In order words, this paper proposes a new test of co-cointegration based on ICA. This is particularly useful as standard co-integration analysis assumes normality which is unlikely to be true for most high frequency financial time series. Thus, the proposed technique is particularly suitable for analysing high frequency financial time series data, such as stock prices and exchange rates.

The paper then proposes a simple model of spot and forward exchange rates which assumes that both rates are linear combinations of two unobserved components, namely, efficient exchange rate and market noise. The paper shows that the proposed co-integration test can be applied to the model in order to differentiate the efficient exchange rate and the market noise.

This paper applies the proposed method to the daily US/Australia spot and forward exchange rates. By analysing the dynamics in the efficient rates and market noise, this paper obtains evidence against some of the standard assumptions underlying conventional exchange rate models and market micro-structure noise.

Keywords: *Blind source separation, Independent component analysis, Cointegration rank, Efficient exchange rate*

Volatility spillovers for stock returns and exchange rates of tourism firms in Taiwan

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Abstract: This paper examines the size effects of volatility spillovers for firm performance and exchange rates with asymmetry in the Taiwan tourism industry. The analysis is based on two conditional multivariate models, BEKK-AGARCH and VARMA-AGARCH, in the volatility specification. Daily data from 1 July 2008 to 29 June 2012 for 999 firms are used, which covers the Global Financial Crisis. The empirical findings indicate that there are size effects on volatility spillovers from the exchange rate to firm performance. Specifically, the risk for firm size has different effects from the three leading tourism sources to Taiwan, namely USA, Japan, and China. Furthermore, all the return series reveal quite high volatility spillovers (at over sixty percent) with a one-period lag. The empirical results show a negative correlation between exchange rate returns and stock returns. However, the asymmetric effect of the shock is ambiguous, owing to conflicts in the significance and signs of the asymmetry effect in the two estimated multivariate GARCH models. The empirical findings provide financial managers with a better understanding of how firm size is related to financial performance, risk and portfolio management strategies that can be used in practice.

***Keywords*:** *Tourism, Size effects, Small-firm effects, Financial performance, Spillover effects, MGARCH, VARMA, BEKK*

Diagnostic checking for Non-stationary ARMA Models: An Application to Financial Data

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Abstract: This paper first derives the limiting distributions of the residual and the squared residual autocorrelation functions of the nonstationary autoregressive moving-average model, respectively. We then use them to construct two portmanteau statistics for testing the adequacy of the fitted model. Simulation results show that the tests have reasonable empirical sizes and powers in the finite samples.

Keywords: *Portmanteau test, Nonstationary ARMA, Residual ACFs, Squared residual ACFs*

The International Technology Diffusion Effect of Cross-Border and Cooperative Patents

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Abstract: With the advent of globalization, economic and financial interactions among countries have become widespread. Given technological advancements, the factors of production can no longer be considered to be just labor and capital. In the pursuit of economic growth, every country has sensibly invested in international cooperation, learning, innovation, technology diffusion and knowledge. In this paper, we use a panel data set of 40 countries from 1981 to 2008 and a negative binomial model, using a novel set of cross-border patents and joint patents as proxy variables for technology diffusion, in order to investigate such diffusion. The empirical results suggest that, if it is desired to shift from foreign to domestic technology, it is necessary to increase expenditure on R&D for business enterprises and higher education, exports and technology. If the focus is on increasing bilateral technology diffusion, it is necessary to increase expenditure on R&D for higher education and technology.

Keywords: *International Technology Diffusion, Exports, Imports, Joint Patent, Cross-border Patent, R&D, Negative Binomial Panel Data*

Dynamic Impact Factors and Escalating Journal Self Citations

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Abstract: The paper focuses on the robustness of rankings of academic journal quality and research impact in general, and in Economics, in particular, based on the widely-used Thomson Reuters ISI Web of Science citations database (ISI). The paper analyses journals using quantifiable Research Assessment Measures (RAMs), and highlights the similarities and differences in various RAMs which are based on alternative transformations of citations and influence. All existing RAMs to date have been static, so two new dynamic RAMs are developed to capture changes in impact factor over time and escalating journal self citations. Alternative RAMs may be calculated annually or updated daily to determine When, Where and How (frequently) published papers are cited. The RAMs are grouped in four distinct classes that include impact factor, mean citations and non-citations, journal policy, number of high quality papers, and journal influence and article influence. These classes include the most widely used RAMs, namely the classic 2-year impact factor including journal self citations (2YIF), 2-year impact factor excluding journal self citations (2YIF*), 5-year impact factor including journal self citations (5YIF), Eigenfactor (or Journal Influence), Article Influence, h-index, and PI-BETA (Papers Ignored - By Even The Authors). As all existing RAMs to date have been static, two new dynamic RAMs are developed to capture changes in impact factor over time (5YD2 = 5YIF/2YIF) and Escalating Self Citations. We highlight robust rankings based on the harmonic mean of the ranks of RAMs across the 4 classes. It is argued that emphasizing the 2-year impact factor of a journal, which partly answers the question as to When published papers are cited, to the exclusion of other informative RAMs, which answer Where and How (frequently) published papers are cited, can lead to a distorted evaluation of journal quality, impact and influence relative to the harmonic mean of the ranks.

***Keywords*:** *Research assessment measures, Impact factor, IFI, C3PO, PI-BETA, STAR, Eigenfactor, Article Influence, h-index, 5YD2, ESC, harmonic mean of the ranks, economics, journal rankings*

Generating a Synthetic Population in Support of Agent-Based Modeling of Transportation in Sydney

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Abstract: The complexity of large cities such as Sydney makes planning challenging. There is a growing need for new and evolving tools to assist research and decision-making. Increasingly, planners require sophisticated insights on social behaviour and the interdependencies characterising urban systems. Agent-based modelling as a large and wide-spread scientific modelling technique (that focuses on computer modelling of individuals and their interactions) has recently emerged as a promising tool in this regard with applications to real-world problems in infrastructure, particularly transport planning, of urban areas. An essential element of such an agent based model is a realistic synthetic population that matches the distribution of individuals and households living in a study area as per the demographics from census data. This paper presents an algorithm to construct such a synthetic population that uses only aggregated data of demographic distributions as inputs, and an agent based model which simulates the natural evolutions (ageing, marriage, divorce, reproducing) of this initial population. The significance of the synthetic population developed in this work is in its ability to capture the relationship of individuals in a household and changes in structure of households as individuals undergo natural evolutions. A case study that uses the algorithm to initialise a synthetic population for Randwick (Sydney) in 2006 and evolve this population over 5 years will also be presented. The results of the initial and final population were validated against the Census Data in 2006 and 2011. The paper closes with discussions on the application of this synthetic population to simulate the dynamics interaction between transport and land-use.

Keywords: *Agent-Based Modelling, Combinatorial Optimization Model, Hierarchical Structure, Household Dynamics; Population Synthetiser.*

Agent Based Model of Service Providers and Consumers within a Dynamic Mobile Communications Market

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Abstract: Technological innovation and introduction has become a regular occurrence in mobile communication markets; boosting consumer demand, smarter devices, rich content, and faster network capabilities are some reasons for this market growth. This results in a competitive dynamic market for Mobile Service Providers (MSPs) and introduces tremendous choice for consumers. While making choices, a consumer can either operate automatically with no sense of control or apply effortful mental thinking. The consumer applies rationality in decisions for consuming mobile communication products based on factors such as: usage patterns, budget, and features of the product. We setup consumer agents to mimic such behaviour in a conceptual Agent Based Model (ABM) together with MSPs.

The consumer agents are grouped into evolving friend circles and review their products periodically. The decision making process involves both rational and automatic behaviours. The decision making process can be divided into five stages according to consumer decision making literature: 1) problem recognition, 2) information search, 3) alternative evaluation, 4) purchase decision, and 5) post-purchase behaviour; in the ABM consumer agents follow such a rational process mixed with considerations of network externalities or historical preferences that aren't always efficient. Consumer agents manage several preferences such as: call-usage, product-review time frames, and reasons for changing products. These preferences are adjusted to setup varying market conditions to create diverse set of simulation scenarios.

For the other side of the market - three MSPs are setup in the model. These MSPs compete by altering features and pricing of their offering. The first MSP (MSP1) always applies a monopoly strategy in which the price is high, features are low, lock-in is lengthy, and provides no start-up incentives (sponsorship). The second entrant, MSP2 creates a copy of the monopolist product, and alters it by applying strategies such as reducing the cost and length of lock-in, or increasing sponsorship and value of the product. The third entrant, MSP3 creates a copy of either MSP1's or MSP2's product and applies it's own strategies similar to MSP2. When MSPs detect changes in the market, they compete with one another applying strategies in-order to expand consumer-base and profits while appreciating consumer preferences. MSP strategies are represented using game trees.

The variation in consumer preference scenarios ranges among value-based and influence-based considerations. Value-based decisions consider the costs to the consumer for making certain amount of phone-calls, defined by historical usage patterns. Influence-based decisions incline consumers to utilise a popular product among their friends. These scenarios merged with the game tree of MSP strategies leads to a set of 72 variations of simulation scenarios.

The ABM allows setting up market scenarios to understand cause and effect of network economic factors. We model most common factors such as cheaper pricing, better features, network effects, and switching costs. The results become increasingly complex as a combination of factors are present at once.

The results show how presence of network effects can capture a large number of consumers in inefficient deals and how existing network externalities impair a MSP's entry into market. The model is able to show how switching costs can delay consumers considering alternatives. These delays allow the losing MSP to rectify pricing and adjust features, in-order to revive their offerings in the market. We setup market representations of monopoly, duopoly, and third entrants. The model provides a means to experiment varying configurations of products to learn about possible outcomes and realisations of market.

Keywords: *Agent Based Model, Pricing, Decision Making, Consumers, Mobile Market, Game Theory*

Modelling Extreme Winners and Extreme Losers in New Zealand Stock Exchange

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Abstract: This paper analyses both common factors and differencing factors that can assist in identifying extremely good performance stocks and extremely poor performance stocks on New Zealand Stock Exchange market (NZX). Adopting the two-stage approach of Beneish, Lee, and Tarpley (2001), the study firstly estimates a model that is able to identify extreme performers relative to a control group within the fourth quarter each year starting from 1994 to 2010. In the second stage, this study contrasts extreme winners and extreme losers within the subset of predicted extreme performers. Findings of the study show that extreme samples are found to have lower market capitalization, lower price before portfolio formation date, and less number of available estimates. In addition, stocks belong to Winners' sample is expected to have lower closing price before the portfolio formation date than Losers' stocks. Extreme samples are also found to have higher standard deviation of return in the prior 6 months before the formation date, and higher ratio between highest closing price and lowest closing price in prior 30 days before the portfolio formation date. Findings of this study are beneficial to fund managers and investment analysts in portfolio construction and stock picking strategies.

Keywords: *Extreme stocks; firm characteristics, trading characteristics; market multiples, fundamental variables*

Modelling the volatility-timing of funds under CPF investment theme

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Abstract: The performance measure of funds has been an important topic in the past few decades. In recent years the conditional models on return and volatility have become popular in studying the funds' performance measure, but most of these studies focus on the US funds and a few on the Asian-based funds. The purpose of this study is to examine the volatility-timing performance of Singapore-based funds under the CPF (Central Provident Fund) Investment Scheme and non-CPF linked funds by taking into account of the currency risk effect on internationally managed funds.

The CPF investment scheme was introduced in 1986 by the Singapore government in order to enhance CPF members' funds for retirement. CPF members usually withdraw money for house purchase, while male and high income earners involve in more risky investment with their CPF saving. The CPF board sets up strict admission criteria for investment products, especially for funds which tend to enter the CPF investment scheme. Fund management companies with intention to enter the CPF Investment must have at least S$500 million fund managed in Singapore with minimum three fund managers. One of fund managers must have at least 5 year experience in fund management. Moreover, foreign funds recognized by the Monetary Authority of Singapore (MAS) are allowed to apply for the inclusion of CPF investment scheme, provided that they are a member of the Investment Management Association of Singapore and also have to submit a representative agreement of foreign funds or their mangers. There are 28 fund management companies under the current CPF investment scheme. Since 1 February 2006, the revised benchmark requires new-entry funds to be above the top 25% among their global peers. Compared with the existing funds within the risk level under CPF Investment Scheme, new funds are also required to have lower-than-median expense ratio. A good historical performance for at least 3 years is desirable. In addition, sales charges for fund under CPF Investment Scheme must be less than 3% from 1 Jul 2007.

Given the strict entry criteria, it is an interesting question to ask if the CPF funds are "safer and better performed funds" as people expected. In this study we empirically assess whether the funds under CPF Investment Scheme outperform non-CPF funds by examining the volatility-timing performance associated with these funds. The volatility-timing ability of CPF funds will provide CPF board with a new method for risk classification. In particular, we employ the GARCH models and modified factor models to capture the response of funds to the market abnormal conditional volatility including the week day effect. The SMB and HML factors for non-US based funds are constructed from stock market data to exclude the contribution of size effect and BE\ME effect. The results show that volatility timing is one of the factors contributing to the excess return of funds. However, the funds' volatility-timing seems to be country-specific. Most of the Japanese equity funds and global equity funds under CPF investment scheme are found to have the ability of volatility timing. This finding contrasts with the existing studies on Asian ex-Japan funds and Greater China funds. Moreover, there is no evidence that funds under CPF Investment Scheme show a better group performance of volatility timing.

Keywords: *volatility timing, GARCH, weekday effect, currency risk exposure*

News Sentiment And States of Stock Return Volatility: Evidence from Long Memory and Discrete Choice Models

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Abstract: This paper examines the relationship between the states of firm-level return volatility and public news sentiment. To incorporate structural breaks into modelling the long memory property of stock return volatility, we develop FIGARCH models that allow the constant in the conditional variance to vary with time. Following this train of thought, we firstly propose a Markov Regime-Switching FIGARCH (MRS-FIGARCH) model that allows the constant term to switch between low and high volatility states. This model is shown to outperform the Adaptive FIGARCH and Time-Varying FIGARCH models with respect to model comparison criteria. It is subsequently used to estimate the smoothing probability and the conditional variance. Second, states of firm-level return volatility are identified by comparing the previously generated smoothing probability with certain thresholds. Then, we employ discrete choice models to investigate the impact of public news sentiment on the volatility states of hourly returns of constituent stocks in the Dow Jones Composite Average (DJN 65). Our news dataset is constructed from the new RavenPack Dow Jones News Analytics database that captures over 1200 types of firm-specific and macroeconomic news releases and their sentiment scores at high frequencies. Estimated results show that news sentiment has various significant effects on the likelihood of volatility states of intraday stock return.

Keywords: *Public Information Arrival, Asset Volatility, News Sentiment, Markov Regime-Switching FIGARCH, Discrete Choice Model*

Modelling High-Frequency Volatility with Three-State FIGARCH models

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Abstract: Fractionally Integrated Generalized Autoregressive Conditional Heteroskedasticity (FIGARCH) models have enjoyed considerable popularity over the past decade because of its ability to capture the volatility clustering and estimate long memory of conditional volatility. However, when structural breaks are present, it is well known that the estimate of long memory will be spurious. Consequently, two approaches are developed to incorporate the structural breaks into FIGARCH framework. First, the intercept in the conditional variance equation is modelled via a certain function of time. The Adaptive-FIGARCH (A-FIGARCH) and Time-Varying FIGARCH (TV-FIGARCH) models are proposed based on this idea. Second, financial series are modelled in separate stages. At the first stage, certain algorithm is applied to detect the change points. FIGARCH model is then fitted, with the intercept (and other parameters) being allowed to vary between change points. A recently developed such algorithm Nonparametric Change Point Model (NPCPM) can be extended to the FIGARCH framework, which is the NPCPM-FIGARCH model. We adopt the second approach but use Markov Regime-Switching (MRS) model to detect the change points and identify three economic states depending on the scale of volatility. This new 2-stage Three-State FIGARCH (3S-FIGARCH) framework and other FIGARCH models are fitted to the hourly data set composed of four major stock indexes, with Gaussian and non-Gaussian distribution assumptions, individually. From the comparison, we find that our model can potentially give an improved fit with better estimate of long memory parameter.

Keywords: *Long Memory, Structural Breaks, FIGARCH, Change Detection*

Modelling the term structure of Japanese bond yields with the Nelson-Siegel model

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Abstract: The Nelson-Siegel (1987) (NS) model has been credited for its high efficacy in the in-sample fitting and out-of-sample forecasting of the term structures of interest rates. The term structure of interest rates, popularly known as the yield curve, is a static function that relates the time-to-maturity to the yield-to-maturity for a sample of bonds at a given point in time. The conventional way of measuring the term structure is by means of the spot rate curve, or yield curve, on zero-coupon bonds. Yet in reality, the entire term structure is not directly observable, which gives rise to the need to estimate it using several approximation techniques. Over the last three decades, various methods to estimate term structures from bond prices have been proposed. In recent years most of the existing studies (as well as major central banks around the globe) have been employing the class of NS models to estimate and construct zero-coupon yield curves.

This paper aims to study the term structure of the Japanese bond yields by employing the NS model vs other non-NS models using five different sets of zero-coupon bond yield rates data obtained from the Bank of Japan covering the period spanning from January 2000 to November 2007. This period has been chosen because it clearly exhibits the liquidity trap problem, which forces all bond yields to remain close to zero for an extended period. We propose 18 different NS models, each with different decay components and time series appendages, against 14 other non-NS models ranging from the simple random-walk model to complicated specifications like the VAR and VECM models. A h-period(s)-ahead out-of-sample expanding window forecast is conducted for each of these 32 different models, using daily, weekly and monthly bond yields of 15 different maturities.

This study has demonstrated that due to the presence of liquidity trap in Japan, out-of-sample expanding window forecasts in general perform inferiorly vis-à-vis other non-NS models, and this is coupled with the other problem of obtaining negative yield forecasts for bonds with shorter maturities. Moreover, the results show that the NS class of models can be useful in forecasting shorter horizons like weeks and days, works better with a decay rate other than the conventional way of treating it as the value that maximizes the loading on the medium-term factor at exactly 30 months, and can work well with time series models such as GARCH and EGARCH in terms of volatility forecasting. It is also found that, when the NS models are used for yield forecasts, the NS-VAR model should be considered since it is up to par against the competitor models, even with liquidity trap at work.

Keywords: *In-sample fitting and out-of-sample forecasting; Japanese bond yields; the Nelson-Siegel (NS) model*

Forecasting Singapore economic growth with mixed-frequency data

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Abstract: In this paper we intend to forecast the economic growth of Singapore by employing mixed frequency data. This study is motivated by the following observations: macroeconomic variables are the important indicators of the economic performance, but they are normally available at low frequencies, e.g. quarterly for GDP and monthly for inflation. In contrast, the financial variables such as stock returns are available at high frequency, and often the asset prices are forward-looking and believed to contain useful information about future economic developments (Stock and Watson 2003). It is therefore an interesting question to raise whether or not one can use the high-frequency financial variables to better estimate and forecast the macroeconomic variables. Using mixed-frequency data in forecasting is clearly against the conventional forecasting models which generally require data with the same frequency. Time-aggregating, such as averaging, of the high frequency data is usually practiced to match the sampling rate of lower frequency data. But time-aggregation always leads to loss of individual timing information that might be important for forecasting. Hence, finding a suitable method to handle the high frequency data is a crucial task for every forecaster dealing with mixed frequency data.

We employ the Mixed Data Sampling (MIDAS) regression model introduced by Ghysels, et al. (2004). MIDAS regressions are essentially tightly parameterized, highly parsimonious regressions that deal with mixed frequency data. It is designed to find a balance between retaining the individual timing information of the high frequency data and reducing the number of parameters that need to be estimated. It is believed to have better estimating and forecasting ability than many other conventional models. A number of studies adopted MIDAS models to forecast quarterly series using monthly or daily financial data, mostly from the US (Anthony 2007; Clements and Galvão 2009).

Singapore is a small open economy, and vulnerable to the global economic conditions. Although its stock market is not comparable with that of the US in term of capitalization, the Singapore stock market performance is believed to be highly correlated with its real macroeconomic variable and contains important information for economic forecasting. In this paper, we forecast one-quarter-ahead Singapore GDP growth rate using Singapore stock market return sampled at various high frequencies. We investigate the forecasting performance from three models: a Mixed Data Sampling (MIDAS) regression model, a direct regression model on high frequency data and a time-averaging regression model. Our results show that MIDAS regression using high frequency stock return data produces better forecast of GDP growth rate than the other two models. Best forecasting performance is achieved using weekly stock return. The forecasting result is further improved by performing intra-period forecasting.

Keywords: *Mixed frequencies; Forecasting; Financial variable; Forecast evaluation*

The relation between news events and stock price jump: an analysis based on neural network

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Abstract: The efficient-market hypothesis states that price movements are extremely efficient in reflecting information flows. Some studies have shown that stock prices are related to news events such as earnings announcements, political events and corporate takeovers, while others have failed to find convincing evidence to relate price changes to news. The aim of this study is to explore the relation between news and abnormal financial market volatility.

We first investigate the Granger causality between news and stock returns. Our results show that stock price change is the Granger cause of news volume and news sentiment; news volume is not the Granger cause of stock price change while news sentiment is the Granger cause of stock price change.

Moreover, we utilize an artificial neural network model to predict stock market collapses by using different volatility parameters. The findings from this study will further our understanding of stock price movements and the reasons for stock market collapses.

Keywords: *Stock price jump, News sentiment, Granger causality, Neural network*

Recoverability of Parameters from Learning Models

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Abstract: Econometric estimation of underlying parameters of learning models has been shown to be problematic (Salmon (2001)). We delve into the causes of that phenomenon. We do so by means of two complementary investigations, using data generated in bidding problems (first price sealed bid auction and Becker-DeGroot-Marschak) by Experience Weighted Attraction (EWA) simulated agents (with true parameters thus known to the researchers). First, we set out to determine how much each of the parameters in EWA affects the agent's attraction to possible strategies, holding constant the random draws involved in the environment in which the agent operates. For the first price sealed bid auction there are large regions of the strategy space where the underlying parameters do not significantly affect the graph of attractions. Our findings regarding the recoverability of EWA parameters in Becker-DeGroot-Marschak are even less promising: large parameter changes are needed for any change in the representation of attractions to register as statistically significant. Second, a further way of examining the sources of potential difficulties in accurately estimating EWA parameters is to see whether one can reject the similarity of attractions that are all generated by the same underlying EWA parameters (but in an environment where the random draws earlier held constant are now redrawn in every trial). In Becker-DeGroot-Marschak, we find that for all but a handful of parameter combinations, one would (incorrectly) reject a null that the same parameters generated the data. A similar statement holds true for the first price sealed bid auction for parameter combinations involving δ near 1, or δ near 1, or both.

Keywords: *Estimation, learning, auctions*

Land use decisions under uncertainty: optimal strategies to switch between agriculture and afforestation

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Abstract: When carbon pricing is part of the economical landscape, agricultural land has the extra option to sequester carbon through afforestation. There is a trade-off between the profits from traditional agricultural crops and from the afforestation income through carbon trading.

In this paper we study the optimal switching strategies between agricultural production and afforestation of agriculture land. The future commodity prices of agriculture products and carbon price are simulated via stochastic asset models. These commodity prices are the risk factors in evaluating the trade-offs between growing crops and afforestation. We model the value for the landholders to change land usage from agriculture production to afforestation, at a sequence of decision making time (annually), as a real option. We employ the least squares Monte Carlo algorithm to calculate the maximum expected value of this land use option, and more importantly, to determine the optimal time to switch land use (stopping rule) and the conditions of switching at each decision time (exercise regions). The valuation framework is based on finding the optimal switching time to maximise the expected discounted cash flow under the uncertainty of the multiple risk factors.

Keywords: *Optimal stopping, least squares Monte Carlo, land use, real options, American option, Bermudian option, afforestation*

Valuing flexible operating strategies in nickel production under uncertainty

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Abstract: With increasing global demand for nickel (which is a key component of stainless steel) the focus of mineral industry is currently on the abundant low-grade nickel laterite reserves. The extraction of nickel from the low-grade laterites is a technically difficult and expensive process and, as a result, the profitability of nickel production projects is highly affected by uncertainty over future market conditions. The project value can be increased by utilizing flexible operating strategies in response to changing future market conditions and Real Options analysis provides a suitable tool for optimizing flexible operating strategies over a long planning horizon in the face of uncertainty.

This paper presents the first study on the valuation of flexible operating strategies in a realistic nickel laterite production system under uncertainty of nickel price and exchange rate. In this paper, the production of ore from the three hypothetical nickel laterite mines being fed to a central processing facility is studied. The common features of nickel laterite production, such as a two-fraction (limonite and saprolite) structure of the laterite ore body, layering of each fraction, with different ore grades (concentration of nickel) in each layer, and a simultaneous mining of several ore bodies, are incorporated into the model.

It is common in the minerals industry that the ore from each mine is blended to provide as constant a feed rate and grade as possible to the processing facility. However, such a constant feed strategy may not generate the best financial return. In this paper, we investigate whether higher returns can be achieved by adopting a flexible strategy of switching, at prescribed intervals of time, between different feed rates of ore from the three mines that have different quality of nickel laterite. Such flexible strategy allows the operator to change the production rate of nickel in response to changing projected market conditions.

In this paper, we use an approximate stochastic dynamic programming framework in the form of the Least Squares Monte Carlo (LSM) method, which we extend to multiple switching options problem that incorporates complex features of nickel laterite production. In addition, an approach that combines a genetic algorithm (GA) with the Monte Carlo simulations is developed for preliminary assessment of options and for estimating the upper bounds on the strategy values.

We compare the value (in terms of the expected discounted cash flow) of the optimal profit-maximising switching strategy for 10 year planning horizon with the NPV value of a constant feed strategy, commonly used in the mining industry. Numerical results show that the flexibility to selectively blend the ore from each mine in response to projected market conditions considerably increases the expected cash flow and the probability of larger profits, while decreasing the probability of smaller profits.

Keywords: *Real options, stochastic dynamic programming, Least Squares Monte Carlo (LSM), nickel laterite, multiple mine-site operation, genetic algorithm*

On adoption of new technology under uncertainty

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Abstract: Investment in new or improved technology is among the most important decisions that companies make, because of the initial cost associated with technology adoption and the impact on company's performance over many years. Company's decision about adoption of new technologies is a trade-off between the cost of making a mistake by adopting too soon and the opportunity cost of waiting for arrival of even better technology. The uncertainty in the speed of new technology arrivals and the extent of technological improvements influences the adoption decision.

This paper continues the line of research that considers the innovation process as a stochastic process with the improvements in new technology described by the Poisson jump process. The focus of early research was on innovation process characterised by a single stochastic variable (namely, the technological efficiency parameter) describing the extent of technology improvements. A critical (threshold) value of the efficiency that triggers technology adoption was established for such a case.

This paper studies the situation common in the minerals processing industry, where not only the efficiency of new technology under development, but also its operating costs may change in a random fashion. This paper extends previous research to the following situations: (1) the efficiency of new technology remains unchanged, while the operating costs decrease randomly, following the Poisson jump process; (2) both the efficiency and the operating costs of new technology change in a random fashion. This case studies two possibilities: (a) the operating cost is a function of the efficiency, and (b) both the efficiency and the operating costs of new technology follow the Poisson jump process with independent jump sizes but the same arrival times.

This paper establishes, for the first time, a threshold curve that separates the plane of feasible values of the efficiency and the operating costs of new technologies into two regions: (1) a waiting region, where new technology adoption is still not optimal and (2) an adoption region. The threshold curve represents a decision boundary that can assist companies in making optimal strategic decisions under uncertainty. Numerical illustrations of the behaviour of the threshold curve with change in model parameters describing the market conditions and the characteristics of the stochastic innovation process are provided. The results show that the adoption decision is significantly affected by the market price of the product (commodity), and the extent of technological improvements the company expects to occur over time.

Keywords: *Technology adoption, technological uncertainty, optimal timing, Poisson technology improvement process, threshold curve*

Quantifying Outcomes in Agricultural Planning

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Abstract: The availability of ground water to irrigate crops is a key component in food security, particularly in developing regions such as the Indo-Gangetic Basin. Policy settings implemented by governmental authorities can have longer term impact on the livelihoods of farming communities in the region, particularly under the uncertainty of future climate conditions. For example, government policies imposing a minimum level on the ground water table in an agriculture region may result in insufficient ground water available to irrigate a given area of crop, and so the cropped area may have to be reduced consequently.

We have developed a model that computes the cropped area that keeps the water table level above a critical value under the uncertainty of future rainfall scenarios. We use a water balance model to predict the change in water table level caused by growing a fixed area of a particular crop over one year with a given annual rainfall. We then model the annual rainfall as a stochastic process and use Monte Carlo simulations to generate stochastic annual rainfall paths, and adjust the cropped area to maintain the underground water table above a critical level in response to each stochastic annual rainfall path by using the water balance model.

We have implemented an optimization procedure that maximises the Sharpe ratio for each year that allows farmers in a region to allocate land to crops in a manner that maximises returns while minimising risk. Starting with land allocations determined through a simple portfolio optimization, we found that considering the effects of rainfall on cropping allocations in addition to accumulating the future cash-flows with a penalty for switching cropping allocations causes a significant difference in cropping allocations when compared to the simple single period optimization scheme.

Our results suggest that the effect of uncertain climate through rainfall in conjunction with certain policy settings may cause a change in optimal cropping land allocations. Further work will focus on developing an optimization model that computes a globally optimal solution, taking into account scenarios where the crop prices do not follow the expected future trajectories.

Keywords: *Decision-making under uncertainty, portfolio optimization, stochastic process*

When to Bite the Bullet? - A Study of Optimal Strategies for Reducing Global Warming

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Abstract: This work is based on the framework proposed by Conrad (1997) to determine the optimal timing of an investment or policy to slow global warming. While Conrad formulated the problem as a stopping rule option pricing model, we treat the policy decision by considering the total damage function that enables us to make some interesting extensions to the original formulation. We show that Conrad's framework is equivalent to minmization of the expected value of the damage function under the stochastic optimal stopping rule. We extend Conrad's model by allowing for policy cost to grow with time. In addition to closed form solution, we also perform Monte Carlo simulations to find the distribution for the total damage and show that at higher quantiles the damage may become too large and so is the risk on the global economy. We also show that the decision to take action largely depends on the cost of the action. For example, in the case of model parameters calibrated as in Conrad (1997) with a constant cost, there is a rather long wait before the action is expected to be taken, but if the cost increases with the same rate as the global economy growth, then action has to be taken immediately to minimize the damage.

Keywords: *Stochastic optimal stopping rule, global warming, Monte Carlo simulations*

The Choice of Stochastic Process in Real Option Valuation: Selecting Multiple Factor Models

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Abstract: The choice of a stochastic process is an issue of great relevance in the assets valuation modeling aiming to represent uncertainties related to investments. In the case of real options it can have an impact not only on the project value but also on the investment rule (Dixit & Pindyck, 1994; Schwartz, 1997). Earlier studies on financial options (Black & Scholes, 1973; Cox, Ross & Rubinstein, 1979) and real options (Brennan & Schwartz, 1985; McDonald & Siegel, 1985 and 1986; Paddock, Siegel & Smith, 1988) assumed Geometric Brownian Motion (GBM) for the underlying asset. For valuation of commodities, it is common to use Mean Reversion Models (MRM) (Bhattacharya, 1978; Brennan & Schwartz, 1985; Dixit & Pindyck, 1994), assuming that commodity price might behave randomly in short term but tends to converge to an equilibrium level in the long run reflecting the marginal cost of production. The task of determining the most appropriate process for the underlying stochastic variables is usually not a trivial question and, in some cases, analysts realize that these uncertainties have elements of more than one type of process. In order to generate more realistic models, several authors proposed models with multiple factors that combine different kinds of processes (Schwartz, 1997; Pindyck, 1999; Dias & Rocha, 1999; Schwartz & Smith, 2000). Although the use of these models might increase the asset valuation accuracy, it is not straightforward to select the appropriate multi factor model. Moreover, real options typically have a feature that allows exercise at any time before maturity. Thus, valuation of real options requires numerical methods. In the case of one or two-factor models, one can use the finite difference or tree methods to solve corresponding partial differential equations. However, in the case of models with more than two factors, one has to resort to special Monte Carlo approaches such as the least square Monte Carlo method suggested in Longstaff and Schwartz (2001).
This paper discusses the choice of stochastic process in real option valuation and useful tests and considerations to resolve this task: Dickey Fuller Test, Variance Ratio Test, Q-Q plots, autocorrelation, likelihood ratio test, Akaike information criterion, Bayesian information criterion, Bayes factors, direct calculation of model probabilities, deviance information criterion, out-of-sample or cross validation, in-sample errors, hedging errors and sensitivity analysis. We also present a set of empirical examples using real datasets and some simple real option applications in order to discuss the effect of stochastic process choice in the analysis.

Keywords: *Stochastic process, real options valuation, multiple factor models, model choice*

Linkage network of biserial queues with a multistage flowshop scheduling in fuzzy environment

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Abstract: This paper addresses the study of a linkage network of biserial queues linked to a common server with a multistage flowshop scheduling system having '*m*' machines or servers in series under fuzzy environment. Waiting lines or queues are commonly occurred both in everyday life and in a variety of business and industrial situations. Also, the flowshop scheduling is an important task when a number of jobs are to be processed through a series of machines or servers in an order. It is usually assumed that the various arrival rates, service rates and processing times of jobs/tasks are exact. However, the real world is complex and the complexity is due to the uncertainty. To express this uncertainty, the concept of fuzziness is introduced in the queuing-scheduling linkage model. Fuzzy sets theory provides a mathematical way to represent uncertainty, vagueness and fuzziness in humanistic systems. If the various arrival and service rates are expressed by possibility rather than probability, the fuzzy queuing methods would be more realistic than classical queuing theory methods. The α-cut approach and various fuzzy arithmetic operations are used to estimate the uncertainty associated with the input parameters. The objective of the paper is to develop an algorithm to optimize the mean queue length, average waiting time and total elapsed time for the proposed queue-scheduling linkage model in fuzzy environment. The efficiency of the proposed algorithm is tested by a numerical illustration.

Keywords: *Biserial queues, arrival rate, service rate, waiting time, mean queue length, processing time, completion time, fuzzy number*

Probabilistic Forecasting of Wind Farm Output

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Abstract: We have previously developed a short time scale forecasting tool for solar radiation [Huang et al., 2013], and also a mechanism for estimating the conditional variance of wind farm output at particular time scales using data at a higher frequency, see [Agrawal et al., 2010, 2013]. The term conditional variance reflects the idea that the variance is changing with time (heteroscedastic) rather than being homogeneous in time (homoscedastic). In this paper, we will describe the application of the solar radiation forecasting tool (which is referred as CARDS model) to wind farm output to obtain forecasts of the level of output on two specific time scales, five minute and half hour. These are the time scales at which the Australian Electricity Market operates. Hence for efficient operation of the electricity grid, it is crucial to have knowledge of forecast of wind energy 5 minute ahead as well as half an hour ahead together with appropriate error bounds. This is exactly the aim of this paper which we achieve using the techniques developed in [Huang et al., 2013] and [Agrawal et al., 2013].

In more explicit terms, knowledge of $\{F_\tau\}_{\tau=t_0}^{t}$, the history of the wind energy output series up to time t allows us to forecast the level of output at time $t+1$, this we achieve using the forecasting tool developed in [Huang et al., 2013]. We then estimate the conditional variance at time t using the techniques developed in [Agrawal et al., 2013]. To facilitate this, we did have high frequency data available at the 10 second time scale. Once we obtained a time series of conditional standard deviation, $\{\sigma_\tau\}_{\tau=t_0}^{t}$, up to the current time step t, we reinvoke CARDS model to obtain a forecast of the conditional standard deviation at time $t+1$, that is, to get $\hat{\sigma}_{t+1}$. Upper and lower bounds of the forecasted wind farm output are thus constructed as $F_{t+1} \pm r\hat{\sigma}_{t+1}$ where r is a positive real number.

An interesting outcome is that 93.5% of the data coverage is contained in the interval $F_{t+1} \pm \hat{\sigma}_{t+1}$ for the 30 minute ahead forecast, while for 5 minute ahead forecast 94.2% of the data coverage is contained in the constructed interval $F_{t+1} \pm r\hat{\sigma}_{t+1}$ with $r = 0.65$. In other words, a lower rate of conditional standard deviation suffices to contain most of the observations at the 5 minute time scale.

This allows us to not only have a forecast of the output but to also put error bounds on that forecast. This type of information is crucial for efficient operation of the electricity grid. This is particularly true in South Australia where wind farms provided 26 % of the electricity generation in the financial year ending June 2012.

Keywords: *CARDS model, high frequency data, conditional variance, forecasting, wind energy*

Coordinated charging of electric vehicles

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Abstract: Electric vehicles recharged from renewable energy sources will play an important role in reducing the key adverse impacts of transport: air pollution, depletion of oil resources, and CO_2 emissions. But they will also add to the demand for electricity. Most electric vehicles will be charged at home, overnight. If they all charge at the same time, during the evening peak, they could cause the electricity supply of households or streets to become overloaded. Increases in peak demand ultimately require upgrades to the transmission and distribution infrastructure, which add significantly to the cost of electricity.

Time-of-use tariffs can encourage users to shift their demand to times when electricity is cheaper because demand is usually lower. But to better manage the demand for electricity and control peak demand, we need appliances, including electric vehicles, that respond in real time to changing supply conditions by shifting their demand. Ultimately, having demand that can respond to the available supply will allow greater use of variable, renewable energy sources.

An electric vehicle will typically need to charge for a few hours overnight. Coordinating the charging of electric vehicles distributed over many premises in an area can smooth the total demand in that area. In this paper we describe a simple load control system that uses signals broadcast from street transformers, typically servicing 30–50 premises, to influence the behaviour of smart appliances in the supplied premises to control the demand profile.

Keywords: *Electric vehicles, charging, demand management*

Multivariate Forecasting of Solar Energy

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Abstract: When methods for forecasting solar radiation time series were first developed, the principal applications were for estimating performance of rooftop photovoltaic or hot water systems. If there were significant errors in the forecast, the consequences were not severe. In recent times there has been increasing development of larger solar installations, both large scale photovoltaic and also concentrated solar thermal. In order to first influence financial backers to participate in their development, and also to potentially compete in the electricity markets, better forecasting models are required than simple Box-Jenkins models, such as those outlined in Boland (2008). In Huang et al (2013), we developed a combination model linking a standard autoregressive approach with a resonating model borrowed from work on dynamical systems, and also an additional component that greatly enhances forecasting ability. This model was developed for a solar radiation series at a single site.

In this article I give an introduction to the tools needed for the multivariate forecasting of solar radiation. The modelling was developed for three sites in Guadeloupe, approximately 20 km. jointly from each other. One would expect significant cross correlation between the sites since they are affected by a common climate influence, Les Alizes, the Trade Winds. Thus, cloud bands inevitably pass over the sites at regular intervals. I demonstrate the techniques required to pre whiten the data (as far as possible) for a single site. The next step involved checking the cross correlation of the noise between sites, finding significant correlation between the sites at time t and also between the values at time t and time $t-1$. A subsequent one lag multivariate time autoregressive model was estimated. It was hoped that the three noise variables resulting from this modelling would be iid. However, this was not to be the case and all three noise series exhibited conditional heteroscedasticity. In this case, ARCH models sufficed to describe this behaviour.

Keywords: *Time series forecasting, multivariate series, ARCH model, CARDS model*

A solar forecasting model based on a fractional Brownian motion

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Abstract: Fluctuations in solar radiation cause problems to electrical power producer's in photovoltaic farms due to the speed of time response of PV systems. Power produced by PV panel follows the change in solar irradiance level varying according to the presence of cloud shadows. That is why tools need to be developped to anticipate the occurrence of lack of productivity.

In this work a method to forecast solar radiation is presented. This method is based on a mathematical approach using weather time-series.

The goal of forecast is twofold : to identify the pattern in a time-series and to predict the future path. At first the prediction method considered uses fractal analysis techniques. Afterward fractional brownian motion is used to forecast the evaluation of solar radiation.

Firstly to setup this method an algorithm is performed to characterise time series variation. At the beginning, several steps are performed:

- Variation scales of solar radiation are identified. Transition phases for damages and callback balance are analysed.
- Fractal nature of radiation signal is performed and its dimension is identified. Classical R/S analysis allows to identify long memory nature of the observed physical phenomenon.
- Using wavelet tools, multi-scale time series decomposition is performed. This tool allows to provide information about the local signal behavior at different scales.
- Parameter driving the trajectories regularity is evaluated in accordance with the history of signal. This parameter traduces the degree of long-range dependence. The singularity spectrum pinpoints local parameter lower than 0.5 corresponding to short-range strong persistence of phenomena and sometimes parameter higher than 0.5 corresponding to long-range strong persistence.

Looking for only one exponent as usually done seems to be impossible because the radiation signal depends on the evolution of several others meteorological parameters. So the nature of the self-similarity varies as function of time. Relation between this local coefficient at the fractal dimension of support is given.

Secondly these parameters are then used in the fractional brownian model. Fractional Brownian motion (FBM) process $B_H = B_H(t)$ is a self-similar process with stationary increments and self-similarity parameter $0<H<1$. Usually the difficulty lying in the local estimations of time-varying scaling exponents for locally self-similar processes. Relationship between this H parameter and the fractal parameter characterising experimental data in the first step is then established.

Finally experimental validation of the method is done by comparing simulated and observed radiation signal in situ.

Keywords: *Self-similar process, fractional brownian motion, multifractal formalism, wavelet, time series forecasting*

Review of Technologies and Optimisation Methods for Integrating Renewable Energy Sources and Storage Within the Australian National Energy Market

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Abstract: Renewable energy generators such as Concentrated Solar Thermal (CST), Photovoltaic (PV), wind, wave and tidal power do not always generate power when it is needed, and so there is an increasing need for energy storage. For thermal systems, the storage could be thermal energy storage at the generator or electrical storage at the generator or within the electrical network.
With the proliferation of non-scheduled generation from renewable electrical energy sources such as there is an ever present need for enabling scheduled generation via the incorporation of energy storage; either as from directly coupled Thermal Energy Storage (TES) at the source or distributed Electrical Storage Systems (ESS) within the electrical network or grid.
The aims of this paper are twofold: to review the existing and emergent storage technologies and to survey the most appropriate optimisation techniques in determining the storage size and the subsequent optimal operation of the system within the context of the Australian National Energy Market (NEM).
Firstly, a review for storage technologies is performed to establish sources for indicative characterisations of energy density, storage containment, conversion efficiency, charge/discharge rates and associated costing.
The survey of optimisation techniques is partitioned into those methods most appropriate for various time scales. That is, from “whole of year”, seasonal, monthly, weekly and daily averaging to those best suited matching the Australian National Energy Market bid timing of five minute dispatch pricing, which is then averaged on the half hour to determine the spot price for trading settlement.
The paper concludes with the selection of what we believe to be the most promising research directions to determine the optimal sizing and operation of storage within the grid for scheduled generation from renewable electrical energy sources.

Keywords: *Thermal Storage, Electrical Storage Systems, Optimisation, Five Minute Bidding, Half Hour Trading Cycle*

Synthetically Interpolated Five-minute Direct Normal Irradiance

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Abstract: The electricity generated from Concentrated Solar Thermal (CST) systems is mostly influenced by the amount of Direct Normal Irradiance (DNI). The majority of DNI values found in both historical and Typical Meteorological Year (TMY) data are hourly means. However, hourly data is too infrequent to capture the transient effects of clouds. High temporal resolution DNI is required to capture these effects on DNI and subsequent influences on CST output.

This paper demonstrates a method where five-minute DNI data from one location is used to develop synthetic variations in the hourly data from another location.

We use five-minute DNI from Adelaide, South Australia, where real five-minute data is available. Five-minute clear sky ratios (ratio of observed DNI to modelled perfect clear sky DNI) are calculated for each 5-minute time period. Hourly clear sky ratios are calculated for each hourly time period. The hourly ratio identifies a clear sky bin into which the twelve five-minute ratios corresponding to the hourly ratio are placed. The result is clear sky indexes each containing five-minute ratios that capture how five-minute DNI fluctuates for each clear sky index.

The process for generating synthetically interpolated five-minute DNI from hourly DNI is straightforward. Hourly clear sky ratios for each hourly time period are calculated to identify the clear sky index from which 12 five-minute synthetic clear sky ratios are bootstrapped (resampled with replacement) for each hour. The synthetic five-minute ratios are multiplied by the five-minute modelled perfect clear sky DNI to give synthetically interpolated five-minute DNI.

Comparisons between synthetically generated five-minute DNI and observed five-minute DNI are made for Adelaide to determine the performance of this method. A mean bias deviation (MBD) of -0.4% and a normalised root mean square deviation (NRMSD) of 16.3% compares favourably with other methods described in the literature, which have a MBD of 0.3% and NRMSD of 31%. The level of variation in the synthetic compares well to the observed with standard deviations of 390.0 and 391.3 respectively.

Of particular interest is how well the model performs when applied to hourly mean DNI for Woomera South Australia. A MBD of -1%, a NRMSD of 15% and standard deviations of 373.5 and 372.4, for the synthetic and observed five-minute DNI respectively, indicate the method is also performing well for Woomera. It is important to note the synthetic DNI for Woomera is derived from a model based on five-minute DNI from Adelaide.

This is an important result because it means the method could also be applied to other locations where only hourly DNI exists. Therefore, not only is the temporal resolution of DNI extended to five-minutes, but the spatial coverage of five-minute DNI is also extended. These results are important in determining the role solar energy will play in a 100% renewable energy system.

Keywords: *Direct Normal Irradiance, DNI, solar radiation, interpolated*

Sensitivity analysis for concentrating solar power technologies

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Abstract: There are potential reductions in greenhouse gas emissions to the atmosphere through the generation of elec-tricity from renewable energy sources. Wind power and photovoltaic panels are well-developed technologies now, and have achieved significant reductions in costs as their industries matured. Renewable energy can also be generated through large-scale solar thermal plants, whereby a field of solar collectors concentrate the sun's energy to heat a fluid that is then passed to a conventional steam generator. This technology is in a develop-mental stage, with the benefits from learning from experience with pilot plants, from mass production, and from innovation not yet obtained.

The Australian Solar Thermal Research Initiative (ASTRI) is a federal government program to investigate technologies that will reduce the cost of electricity produced by concentrating solar power (CSP) plants. One aspect of the program is to develop a methodology to create a baseline economic model for the costs of typical CSP plants, and use this to assess the potential for cost reductions of research activities. Part of the methodology is the System Advisor Model (SAM) developed by an ASTRI partner, the U.S.'s National Renewable Energy Laboratory. SAM is an industry standard model for comparing the performance of solar thermal or photovoltaic plants. The analysis reported here, and the framework for the economic model for the ASTRI program, uses SAM and solar data from Longreach, Queensland.

This paper reports on basic outcomes from the SAM model for two solar tower systems, one with storage and one without, comparing results mainly in terms of the levelised cost of electricity achieved by the plants. Standard settings for SAM are used, some of which are later systematically varied during sensitivity analysis on model inputs.

Keywords: *Concentrating solar power, Sensitivity analysis, Levelised cost of electricity*

Transmission Loss Modelling and Analysis with Multiple Linear Regression

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Abstract: Unit commitment (UC) and economic dispatch (ED) are two crucial optimisation problems in the short term operational planning of power systems. For a given scheduling period, UC determines the optimal set of generating units to be in service whereas ED determines the economic distribution of generation values for a known set of generators. Both of these problems are modelled as aggregated supply and demand problems, and require an estimate of the transmission loss. Therefore the accuracy of the approximated transmission loss within these problems is vital in ensuring the optimality and feasibility of the solutions. The increasing penetration of renewable energy (RE) technologies into the grid has increased the volatility of the transmitted power, making it harder to approximate the transmission loss using existing techniques. A robust and reliable approximation is required, valid across a wide range of transmission values.

Consider a power network with a set of nodes connected by transmission lines, with subset B of nodes with demand and subset N of nodes with generators. Let d_i be the real power demand at node $i \in B$, p_j, the real power generated at node $j \in N$ and L, the total real power transmission losses in the system.Without loss of generality let generator node 0 be the slack bus and write $N_0 = N \backslash \{0\}$ for the generation nodes excluding the slack bus. This paper looks into a new way of modelling the aggregated transmission loss, using multiple linear regression. The fitted model's form is

$$L(k) = \sum_{i \in N_0} \sum_{j \in N_0} \alpha_{ij} p_i(k) p_j(k) + \sum_{i \in B} \sum_{j \in B} \gamma_{ij} d_i(k) d_j(k) + \sum_{i \in B} \sum_{j \in N_0} \eta_{ij} d_i(k) p_j(k) + \epsilon(k)$$

where $k = (1, \ldots, n)$ is the observation number, $\epsilon(k)$ is the error and α_{ij}, β_{ij} and η_{ij} are coefficients fitted using least squares. The proposed model does not rely only on a particular base case and does not make simplifying assumptions, as seen in previous models, though we do assume that the topology of the power network does not change. This makes the model more robust than existing approximations.

In this paper the effect of power demand (load) at each demand point, power generation and voltage magnitudes for each generator are tested for eight different scenarios created using J.H. Chows 3-Machine 9-Bus benchmark problem which is quoted in Zimmerman et al. (2011). In each scenario we compare our proposed model with loss approximation models currently used in industry. From the analysis we see that our proposed model outperforms the existing models, and gives good approximations for a wide range of inputs. We also show that the performance measures used to compare the models can be used to determine a best base case.

Finally, we show that by looking at the effect of voltage on how well our model fits, we are able to determine voltage limits for generators that are best, in the sense that they minimise the instability caused to load flows due to improper voltage magnitude values.

Keywords: *Transmission loss modelling, Multiple Linear Regression, Performance Measures, Voltage Instability*

Expanding renewable energy by implementing Demand-side Integration

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Abstract: The energy sector faces numerous challenges, such as dealing with depleting fossil resources and increased environmental awareness. Among different options, the Smart Grids solutions such as Demand-side Integration (DSI), also known as Demand-Side Management, are attractive alternatives to expand renewable energy sources. However, it is difficult to assess to what extent demand-side integration (Demand Response -DR- and Energy Efficiency -EE-) could curb the trend. Generally, models evaluating DR restrict their considerations to changes in local energy systems over short periods of time and classical planning models show weaknesses for addressing demand management. Consequently, results may provide unrealistic options for future power systems regarding this concern as demand-side integration may have both nationwide and long-term benefits for the energy system.

The aim of this paper is to assess the impacts of DSI in future electricity systems using long-term planning models to evaluate the benefits of both DR and EE while considering the development of the power system in the long term. To this end, we propose an approach based on the MARKAL/TIMES models, which makes it possible to evaluate a system's benefits over several decades. These prospective energy system models are useful tools to provide plausible options of the long-term development of the power systems. The MARKAL/TIMES models are demand driven and may consider a wide variety of demand aspects such as electricity, heat, and transport, enabling us the implementation of the different DR programs (load-shifting, peak clipping) and energy efficiency measures :

- Load shifting program aims to flatten the load curve by postponing electricity demand from peak to off-peak periods. The day's total demand has to be fulfilled but it does not matter during which time-slice. The model is only constrained to fulfill the demand during the day, whenever it chooses. Four uses enable this “long-length postponement”: water heaters and machines for washing clothes, dishes and drying clothes.

- The length of postponement of some equipment’s is incompatible with the time-slices used in the model because these are related to the thermal inertia of the building or the equipment. However, electrical devices can be used to prevent load fluctuations, and participate to “short-length postponement”. It is taken that 20% of refrigeration, heating, cooling and ventilation can be stopped to respond to a malfunction in the electricity system.

- Consumers are classified according to behavioral indicators related to their energy use in order to enable different kinds of energy efficiency programs: replacing old appliances with more efficient ones, setting up building renovation works, eliminating standby power.

Our analysis is demonstrated by the case of Reunion Island, which aims to produce electricity using 100% renewable energy sources by 2030, and for which demand response and energy efficiency are also potential solutions for reaching this objective. To ascertain the benefits of DSI, we use the TIMES-Reunion model to evaluate the IND scenario that takes into account the island's energy objective. This scenario includes the hypothesis of lower fossil energy imports than currently, up to 2030, where no imports are considered. This scenario also assumes an upper boundary of 30% electricity production using intermittent energy sources for each time-slice, in line with current legislation. The results show to what extent Demand-side integration makes it possible to flatten the load curve and enable a decrease in the total cost of the energy system in different ways, both in the short and long term.

Keywords : *Long-term planning, MARKAL/TIMES, Demand Side Integration, Smart Grids*

Modelling for the electricity distribution network

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Abstract: Global awareness for cleaner and renewable energy is transforming the electricity sector at many levels. New technologies are being increasingly integrated into the electricity grid at high, medium and low voltage levels, new taxes on carbon emissions are being introduced and individuals can now produce electricity, mainly through rooftop photovoltaic (PV) systems. While leading to improvements, these changes also introduce challenges, and a question that often rises is 'how can we manage this constantly evolving grid?'

The Queensland Government and Ergon Energy, one of the two Queensland distribution companies, have partnered with some Australian and German universities on a project to answer this question in a holistic manner. The project investigates the impact the integration of renewables and other new technologies has on the physical structure of the grid, and how this evolving system can be managed in a sustainable and economical manner. To aid understanding of what the future might bring, a software platform has been developed that integrates two modelling techniques: agent-based modelling (ABM) to capture the characteristics of the different system units accurately and dynamically, and particle swarm optimization (PSO) to find the most economical mix of network extension and integration of distributed generation over long periods of time.

Using data from Ergon Energy, two types of networks (3 phase, and Single Wired Earth Return or SWER) have been modelled; three-phase networks are usually used in dense networks such as urban areas, while SWER networks are widely used in rural Queensland. Simulations can be performed on these networks to identify the required upgrades, following a three-step process: a) what is already in place and how it performs under current and future loads, b) what can be done to manage it and plan the future grid and c) how these upgrades/new installations will perform over time.

The number of small-scale distributed generators, e.g. PV and battery, is now sufficient (and expected to increase) to impact the operation of the grid, which in turn needs to be considered by the distribution network manager when planning for upgrades and/or installations to stay within regulatory limits. Different scenarios can be simulated, with different levels of distributed generation, in-place as well as expected, so that a large number of options can be assessed (Step a). Once the location, sizing and timing of assets upgrade and/or installation are found using optimisation techniques (Step b), it is possible to assess the adequacy of their daily performance using agent-based modelling (Step c).

One distinguishing feature of this software is that it is possible to analyse a whole area at once, while still having a tailored solution for each of the sub-areas. To illustrate this, using the impact of battery and PV can have on the two types of networks mentioned above, three design conditions can be identified (amongst others):

- Urban conditions
    - Feeders that have a low take-up of solar generators, may benefit from adding solar panels
    - Feeders that need voltage support at specific times, may be assisted by installing batteries
- Rural conditions - SWER network
    - Feeders that need voltage support as well as peak lopping may benefit from both battery and solar panel installations.

This small example demonstrates that no single solution can be applied across all three areas, and there is a need to be selective in which one is applied to each branch of the network. This is currently the function of the engineer who can define various scenarios against a configuration, test them and iterate towards an appropriate solution. Future work will focus on increasing the level of automation in identifying areas where particular solutions are applicable.

Keywords: *Electricity distribution grid, decentralised systems, planning and management*

Accounting for renewable energy supply intermittency in energy systems modelling

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Abstract: We report on the development and application of an integer programming model for simultaneously proposing electricity transmission system augmentations and the selection of electricity generation projects over multi-year time horizons. Undertaking network design while simultaneously addressing renewable energy supply variability over time and space is a difficult proposition. It was however a key design requirement for this model, due to the model's intended use as part of studies of plausible scenarios for Australia's energy future to 2050. The model has been successfully utilised within a multi-stage modelling workflow, being preceded by an economic model of the energy sector and followed by a high resolution simulation of the national electricity market. Together the three models flesh out the details of electricity systems of the future, in terms of the location and technologies for individual power plants, the magnitude of transmission line capacity expansions, and the energy and financial flows in the resulting networks. We present the results from various analyses that have been undertaken using the model, with emphasis on the integration of renewable and fossil-fuel supply options to meet end-user demand, and also describe some of the mathematical and systems-development work that was required in order to yield a model which was sufficiently detailed, solvable in reasonable time, and able to be embedded in a powerful yet easy-to-use GIS and database system.

Keywords: *Electricity transmission and generation, integer programming, network design*

Modelling travel and charging patterns of plug-in electric vehicles

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Abstract: Plug-in electric vehicle (EV) technologies are now being offered in various forms by many of the major car manufacturers. These technologies offer several potential benefits, including energy security, utilization of EV batteries as load-balancing devices in electricity grids, and reduction in greenhouse gas emissions. The authors have developed an integrated framework for assessing these opportunities, through a sequence of models describing patterns of vehicle usage and battery recharge. The approach is disaggregated both in space and in time, in order to provide a sound operational basis for impact assessment.

The relevant patterns of vehicle usage are concerned with distance travelled during off-driveway periods (ODPs), and ODP departure and arrival times. In the modelling approach developed by the authors, these patterns are derived from travel surveys carried out by state Government agencies, where survey data is available; elsewhere, they are approximated using information from comparable areas.

The vehicle usage estimates are combined with estimates of the projected number of EVs in each Statistical Local Area to obtain profiles of total charging energy, which in turn are utilized by a suite of algorithms that model battery recharge/discharge processes. The processes modelled by these algorithms include peak and off-peak charging, and off-peak charging combined with vehicle-to-house discharging to support the grid at times of peak electricity consumption. The paper presents the modelling framework and methodology developed by the authors, and summarizes experience and results from a study of Townsville, Queensland.

Keywords: *Travel behaviour; accessibility; electric vehicle; electric vehicle charging, energy demand*

Controlling Micro-CHP Generators as a Virtual Power Plant

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Abstract: Deploying gas generators as a source of combined heat and power (CHP) in residential complexes offers the potential for substantial reductions in overall energy use and greenhouse-gas emissions. Here we use mathematical modelling to predict the operational behaviour of such generators in a hypothetical network of 100 residential apartment buildings.

In our models the generators produce electricity for local needs and for participation in the national energy market (NEM), while delivering space heating and hot water to the residences. The management strategies used optimise economic performance while satisfying the heat and power demands of the residential customers. The heat and power demand data has been synthesised using multiple information sources and is intended to represent a plausible demand pattern for residential apartment buildings in Victoria, Australia.

We present a linear programming based optimisation strategy for controlling micro-CHP generators that provide heating, hot water and electricity for apartment blocks. We assume that the operator of the generators can also participate in the NEM by providing a block of power once a day. Our system assumes that we have perfect prior knowledge about the power and heating demands in the apartment blocks as well as about the prices on the NEM.

By running the optimisation for each day of the year 2012, we show that an optimal strategy would provide about 67% of the annual electrical generation capacity of all generators for local use as well as for export to the NEM. We also show that the variable profit obtained from running the generators is extremely high on days with high NEM prices compared to days with average prices. Where it is unprofitable to operate the generators electricity is purchased from the grid at market rates.

An operator running CHP-generators according to the business model we describe in this paper must make sure that he or she can profit from the days with extreme NEM prices. A business model where the operator can only sell electricity to the occupants of the apartment blocks for the retail price has a much smaller earning potential. Therefore, allowing distributed generation operators with significant capacity to participate in the NEM should greatly encourage the installation of these devices and help reduce price peaks and congestion at the same time.

Our results also show that the savings in CO_2 emissions from using CHP-generators in apartment buildings can be substantial with up to a 52% reduction in annual emissions compared to satisfying heat and electrical demand by conventional means. The CO_2 savings are also strongly influenced by the wholesale prices in the NEM and being able to make use of high prices leads to significant additional savings which is demonstrated by the the amount saved on summer peak days.

In our future work, we want to examine control strategies that do not assume perfect knowledge about prices and demand on the next day but instead use available data like weather forecasts and the price forecasts provided by Australian Energy Market Operator (AEMO), combined with reacting to observed data. We could then use the system presented in this paper as a benchmark for measuring the predictive and adaptive strategies.

Acknowledgement: We acknowledge the valuable help and advice provided by Bill Lilley in the creation of this paper.

Keywords: *Distributed generation, electricity markets, micro-chp*

Performance of wind energy conversion systems under low power density wind regimes

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Abstract: Due to the present day's energy crisis and growing environmental concerns, supplementing our energy base with clean and renewable resources like wind has become imperative. With its steady growth rate over the years, wind energy would become a major player in the clean energy scenarios in the near future. On the other hand, sites with high wind energy potential are becoming scarce due to social, technical and economic reasons and the future wind power developments would more be focused on sites with moderate wind spectra. Keeping this in view, several leading wind turbine manufactures have introduced turbine designs targeting sites with low to medium wind potential. The current investigation theoretically analyzes and simulates the performance of some of these new designs under low power density wind regimes.

Three low wind speed turbines recently introduced by leading wind turbine manufacturers were considered under this study. Performances of these turbines at a representative site falling under the wind class 3 were modeled. The model basically combines the Weibull probability density function of the wind velocity at the site and the velocity – power response of the turbine which is then integrated within the productive functional limits of the turbine. Expressions for the energy yield and capacity factor of the turbine at a given site are presented. Wind Energy Resource Analysis (WERA) tool, which is based on the above models, is then used to simulate the performance of the selected turbines at the representative site. Performance of a conventional turbine at the given site has also been analyzed for comparison.

Results of the simulation indicates that, with reasonably high capacity factors, all the three low wind speed turbines perform well under the low power density wind conditions. The key requirements for the turbines to perform better under low wind regimes have been identified as lowering the cut-in and rated wind speeds, and design improvements for better velocity power response at lower wind spectra.

Keywords: *Wind turbine, wind velocity frequency distribution, power curve, WERA, capacity factor*

Calculation of Effective Permeability in Fractured Porous Media Using Finite Volume Method

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Abstract: This paper focuses on calculation of effective permeability in fractured porous media with blocks matrix using finite volume Computational Fluid Dynamics (CFD) method. This fractured media with blocks matrix can be found in the Enhanced Geothermal Systems (EGS). A fracture network consists of nine square (3*3) rock blocks and the fractures between the rocks. Periodic boundaries are used for four side of the domain, while zero mass flow rate is implemented in the vertical direction and a mass flow rate of 0.0092 kg/s is implemented in the horizontal direction.

Effects of rock material permeability of the rock blocks on the effective permeability of the whole domain are investigated. Five cases with different rock permeability, namely, 0 m^2, 0.1E-7m^2, 0.1E-6m^2, 0.1E-5m^2, and 0.1E-5m^2, are calculated based on the CFD model. It is found that the effective permeability K_x increases significantly as the increase of the rock permeability, indicating the importance of taking into consideration of rock permeability in calculating effective permeability of EGS systems.

***Keywords**:* *Geothermal System, CFD, fracture, Pressure drop, effective permeability*

Calculation of Equivalent Permeability of Different Fracture Intersections in Fractured Porous Media

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Abstract: This paper reports a case study of calculation of equivalent permeability in Hot Dry Rock (HDR) system using an approach based on finite volume Computational Fluid Dynamics (CFD) method. In this case study, mass flow rates of water in two fractures crossing in a 300 mm x 300 mm two-dimensional (2D) block are predicted by CFD method for different pressure drops. The predicted mass flow rates are then used to calculate the equivalent permeability, K_x at x direction and K_y at y direction. A series of angles between these two fractures, α, are investigated and the results of α= 90, 60 and 50 degrees are reported in the paper. It is found that K_x slightly increases (by about 2%) when the angle of fractures decreases from 90 to 50 degrees. The values of K_y reduce by about 21% when the angle of fractures decreases, indicating the permeability is dependent on the heterogeneous property of the block. The developed approach is used to investigate the effects of pressure drops on the equivalent permeability. It is found the values of the equivalent permeability are slightly influenced by the pressure drop values in the investigated ranges.

Keywords: *Computational Fluid Dynamics (CFD), fracture, equivalent permeability, Hot Dry Rock*

Simulation of Biodiesel and Petrodiesel Pollutant Kinetics

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Abstract: Biodiesel is considered as an attractive alternative to petrodiesel for transportation applications. Substituting petrodiesel with domestically produced biodiesel increases energy independence, reduces the carbon footprint, and offers a viable path toward biomass utilisation. It has been found that biodiesel-fuelled engines emit up to 70% lower particulate matter (PM) compared to petrodiesel-fuelled engines, although they emit up to 20% more nitric oxides (NO_x). In this study, simulations are employed to improve the fundamental understanding of biodiesel and petrodiesel combustion under pressure and temperature conditions in engines. n-Heptane is used as the surrogate for petrodiesel fuel and a ternary mixture of methyl decanoate, methyl-9-decenoate, and n-heptane as the surrogate for biodiesel fuel. The choice of chemical kinetic mechanism is a compromise between computational time and accuracy. Four mechanisms are evaluated and a 160-species skeletal chemical kinetic mechanism is employed to model the oxidation of n-heptane. The computational time is shown to increase dramatically as the complexity of the mechanism increases. Soot kinetics is represented using a chemical mechanism that models the growth of soot precursors starting from a single aromatic ring and growing by hydrogen abstraction and carbon (acetylene) addition. NO_x kinetics is represented using the thermal, prompt, and intermediate mechanisms. In the case of the ternary biodiesel surrogate, a 211-species reduced mechanism is employed to model the chemical kinetics. This mechanism was derived as part of this work by combining reactions from the 160-species n-heptane mechanism with reactions from a skeletal 115-species mechanism proposed in the literature. The influence of turbulence is modeled through an imposed strain rate in the simulations.

The computations are carried out using a strained laminar flamelet code (SLFC). In addition to exploring the effect of strain rate (turbulence) on the ignition, extinction, and pollutant formation characteristics, the fundamental chemical pathways that lead to PM and NO_x formation are studied by considering the evolution of precursor species. In general, ignition and extinction of flames in biodiesel combustion are more sensitive to turbulence than in petrodiesel flames. Soot volume fraction is lower in biodiesel combustion compared to petrodiesel combustion. This is consistent with measurements reported in engines. NO concentration is, however, lower for biodiesel combustion when considering kinetics alone, suggesting that the volume phasing and operating parameters of engines influence observed NO results in engine emissions where NO is observed to be higher in biodiesel-fuelled engines. It is shown that while increasing strain reduces soot formation for both fuels, the reduction is significantly greater for biodiesel suggesting that increased mixing has a greater effect on PM emissions in biodiesel-fuelled engines.

Keywords: *Biodiesel, Kinetics, Soot, Combustion, Engines*

Modelling Ethylene-Hydrogen Jet Flames in the MILD Combustion Regime

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Abstract: Moderate or Intense Low oxygen Dilution (MILD) combustion is a particular combustion regime which offers improved thermal efficiency and a reduction of nitrogen oxide (NO_X) pollutants and soot. In this paper computational fluid dynamics (CFD) is employed to model turbulent jet flames issuing into a hot and diluted coflow stream, with a view to develop fundamental level understanding of the MILD combustion regime. Reynolds averaged Navier-Stokes (RANS) simulations are coupled with the Eddy Dissipation Concept (EDC) turbulence-chemistry model and the computational results are compared with experimental measurements. For the turbulent ethylene-hydrogen (C_2H_4/H_2) fuel jet, a modified k-ε turbulence model, the standard Reynolds Stress Model (RSM), Shear Stress Transport (SST) model, k-ω models, and a modified RSM are considered. Results show that a mesh, constructed with 53610, primarily rectangular, elements with a characteristic length of 0.950mm, is sufficient to model the combustion processes in the MILD configuration of the JHC burner. The most accurate reacting flow field is predicted using the modified RSM, by adjustment of the factor $C_{1\varepsilon}$ to 1.6 from the default 1.44. The RSM is the most computationally expensive model, being an anisotropic extension of the standard k-ε model, however the increased computational cost is small in comparison to the cost of solving the detailed, finite-rate chemistry required for modelling MILD combustion. The modified RSM is therefore deemed to be superior in this application in comparison to the other turbulence models investigated.

Keywords: *Turbulence models, RANS, Combustion, MILD Combustion*

An Artificial Neutral Network (ANN) Model for Predicting Biodiesel Kinetic Viscosity as a Function of Temperature and Chemical Compositions

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Abstract: An Artificial Neural Network (ANN) is a computational modeling tool which has found extensive acceptance in many disciplines for modeling complex real world problems. An ANN can model problems through learning by example, rather than by fully understanding the detailed characteristics and physics of the system. In the present study, the accuracy and predictive power of an ANN was evaluated in predicting kinetic viscosity of biodiesels over a wide range of temperatures typically encountered in diesel engine operation. In this model, temperature and chemical composition of biodiesel were used as input variables. In order to obtain the necessary data for model development, the chemical composition and temperature dependent fuel properties of ten different types of biodiesels were measured experimentally using laboratory standard testing equipments following internationally recognized testing procedures. The Neural Networks Toolbox of MatLab R2012a software was used to train, validate and simulate the ANN model on a personal computer. The network architecture was optimised following a trial and error method to obtain the best prediction of the kinematic viscosity. The predictive performance of the model was determined by calculating the absolute fraction of variance (R^2), root mean squared (*RMS*) and maximum average error percentage (*MAEP*) between predicted and experimental results. This study found that ANN is highly accurate in predicting the viscosity of biodiesel and demonstrates the ability of the ANN model to find a meaningful relationship between biodiesel chemical composition and fuel properties at different temperature levels. Therefore the model developed in this study can be a useful tool in accurately predict biodiesel fuel properties instead of undertaking costly and time consuming experimental tests.

Keywords: *ANN model, Biodiesel, Kinematic viscosity, Temperature dependence*

Thermodynamic Modeling of Ethanol Fumigation in a Diesel Engine

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Abstract: Due to rapidly diminishing international supplies of fossil fuels, such as petroleum and diesel, the cost of fuel is constantly increasing, leading to higher costs of living, as a result of the significant reliance of many industries on motor vehicles. Many technologies have been developed to replace part or all of a fossil fuel with bio-fuels. One of the dual fuel technologies is fumigation of ethanol in diesel engines, which injects ethanol into the intake air stream of the engine. The advantage of this is that it avoids any costly modification of the engine high pressure diesel injection system, while reducing the volume of diesel required and potentially increasing the power output and efficiency.

This paper investigates the performance of a diesel engine, converted to implement ethanol fumigation. The project will use both existing experimental data, along with generating computer modeled results using the program AVL Boost. The data from both experiments and the numerical simulation indicate desirable results for the peak pressure and the indicated mean effective pressure (IMEP).

Increase in ethanol substitution resulted in elevated combustion pressure and an increase in the IMEP, while the variation of ethanol injection location resulted in negligible change. These increases in cylinder pressure led to a higher work output and total efficiency in the engine as the ethanol substitution was increased. In comparing the numerical and experimental results, the simulation showed a slight elevation, due to the inaccuracies in the heat release models. Future work is required to improve the combustion model and investigate the effect of the variation of the location of ethanol injection.

Keywords: *Compression-Ignition Engine, Fumigation, Ethanol, Bio-fuel, Thermodynamic modeling*

Development of a two-dimensional internal combustion engines model using CFD for education purpose

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Abstract: A two-dimensional (2D) computational fluid dynamics (CFD) model of a spark ignition (SI) engine has been developed using the commercial CFD package ANSYS/FLUENT 14.0. This model comprises one cycle of a 4-stroke engine, including intake stroke, compression stroke, power stroke and exhaust stroke. The combustion of the fuel, heptane, is included in this model. The inclusion of combustion helps students to better understand chemical reactions, species transport, and work and heat transfer in the engine. In addition to adding combustion, realistic boundary conditions are used in the current engine model.

The SI engine model has been implemented in a 2-hour CFD practical session in the Level IV undergraduate/postgraduate subject 'Automatic combustion' in the School of Mechanical Engineering at the University of Adelaide. This is the first time, to the best knowledge of the authors, that CFD has been used as a hands-on tool in internal combustion (IC) engine education. This paper presents some details of the engine model and some predicted results including temperature, velocity fields, species concentration and pressure profiles.

Keywords: *Computational Fluid Dynamics (CFD), internal combustion engine, engineering education*

Scoping the budding and climate impacts on Eucalypt flowering: nonlinear time series decomposition modelling

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Abstract: Often a phenophase such as flowering is considered in isolation. However, the timing of each phenophase is influenced by the previous (e.g. bud development rate influences the quantity and timing of flowering). This relationship has rarely been examined for eucalypts. In eucalypts, the development of buds often commences in a different season or, if in the same season, in different years, Climate influences on budding are therefore different to flowering. The effects of climate on the flowering of species has been previously determined (Hudson and Keatley, 2010b; Hudson et al., 2010, 2011b; Keatley and Hudson, 2000). This study includes modelling the influence of buds, in addition to climate, with respect to flowering. The Generalized Additive Model for Location, Scale and Shape (GAMLSS) is used to model the relationship between climate (mean monthly minimum, maximum temperatures and rainfall) during bud development and the flowering cycles of 2 eucalypt species (*Eucalyptus leucoxylon* and *E. tricarpa*) from the Maryborough region of Victoria between 1940 and 1962. Monthly behaviour (start, peak, finish, monthly intensity, duration and success) in budding and flowering was assessed using the indices of Keatley et al. (1999) and Keatley & Hudson (2007).

Although *E. tricarpa* buds are significantly ($P < 0.01$) positively and linearly related to higher minimum temperature (≥ 9°C) both flowering and buds decrease significantly with maximum temperature (>21°C) ($P < 0.01$). Models of flowering including current bud status and climate show that *E. tricarpa* flowering is positively related to current budding intensities (buds > 4.5) ($P = 0.0000$) and increases with elevated rainfall (from 40 to approximately 88 mm) ($P=0.045$) ($R^2=60.8\%$). Inclusion of current budding as well as budding intensity 1 to 3 months prior to flowering in the models show *E. tricarpa's* flowering to significantly decrease and cease above 7.7°C minimum temperature, and increase with increased rainfall between appropriately 44 and 93 mm. Budding 2 months prior is a positive influence ($P < 0.007$), combined current budding and budding 2 months prior indicate flowering commences within the budding range of 4 to 6 ($R^2=71.4\%$). For *E. tricarpa* minimum temperature is shown to drive increased budding but is associated with decreased flowering. Maximum temperature is associated with both increased budding and increased flowering for *E. tricarpa;* and flowering increases non-linearly both with elevated rainfall (from 40 -90 mm) and with increased buds. For *E. leucoxylon* buds are significantly ($P < 0.01$) negatively and linearly related to elevated maximum temperature (> 23°C) ($Z = -3.2$, $P < 0.0001$) and buds increase with increasing minimum temperature ((≥ 9°C) ($Z =1.92$, $P < 0.08$, 10% sig). Budding is significantly but nonlinearly influenced by rainfall: rain up to 40 mm has a positive influence and 40 to 80 negative. Models of *E. leucoxylon* flowering, which include current bud status and climate, show that *E. leucoxylon's* flowering is positively and nonlinearly related to current buds (buds > 5.5) ($P = 0.000001$) and decreases significantly with elevated minimum temperature (≥ 8.5°C) ($Z = - 2.38$, $P < 0.0001$) ($R^2 = 42.6\%$). Inclusion of budding 1 to 3 months in the models show *E. leucoxylon* flowering to significantly increase with higher current bud quantity ($Z = 2.57$, $P < 0.0001$) and nonlinearly with respect to bud quantity 2 months prior ($P < 0.005$) - with flowering commencing with bud intensity above 4.5 and decreasing when buds reach 7.0 ($R^2=68.9\%$). This study has confirmed that for flowering to start, buds must have reached a particular maturity, before flowering occurs. For *E. tricarpa* this seems to occur when bud intensity has reached greater than 4.5, with a slightly lower value for *E. leucoxylon,* indicating that this species buds need longer to mature - this in turn further assists in separating the temporal flowering peaks between the two species. Additionally, a maximum flowering intensity is indicated with the inclusion of lagged budding: 6.0 for *E. tricarpa* and 7.0 for *E. leucoxlyon*. The inclusion of lagged budding found that budding two months prior was influential on flowering. Noteworthy is that 2 months is the most common period when temperature has the greatest influence on flowering (Hudson and Keatley, 2010a; Hudson et al., 2011a; Hudson et al., 2011c; Menzel and Sparks, 2006). These results indicate that it might not just be temperature, but temperature influencing the development of buds, which in turns influences flowering. This needs further work and the examination of additional species, but given that flowering is dependent on budding, this postulate makes sense (Primack, 1987).

Keywords: *phenology, Australia, climate and budding thresholds, life-history, GAMLSS*

Mean monthly radiation surfaces for Australia at 1 arc-second resolution

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Abstract: Solar radiation data are useful for many purposes including ecological and hydrological modelling and for assessing available solar energy. Using the new national 1 arc-second DEM, the SRAD model, and national climate, albedo, and vegetation cover data, we have created mean monthly radiation surfaces for Australia: total shortwave on a sloping surface (SWS), total shortwave on a horizontal surface (SWH), the ratio of sloping to horizontal shortwave (SWR), incoming atmospheric longwave (LIN), outgoing surface longwave (LOUT), net longwave (LNET), and net radiation (RNET). The output datasets will be available through the TERN Data Discovery Portal (http://portal.tern.org.au) and the CSIRO Data Access Portal (http://data.csiro.au/dap).

Modelling solar radiation using DEMs can be undertaken with varying degrees of complexity and parameterisations. Calculating the position of the sun and length of the day are relatively straightforward but the effects of clouds, scattering and absorption in the atmosphere, topographic shadowing, and reflection from sloping surfaces make precise calculation of radiation at the surface exceedingly difficult. SRAD models the solar radiation incident upon a sloping surface accounting for the solar geometry on a given day, the surface orientation, shadowing by surrounding terrain and the transmittance of the atmosphere and clouds, and calculates incoming and outgoing longwave radiation based on air and surface temperatures and emissivities. The model uses elevation, slope and aspect, and 12 mean monthly surfaces for albedo, fractional vegetation cover, 9 am and 3 pm cloud cover, minimum and maximum air temperature, and 9 am and 3 pm vapour pressure. The relationship between cloud fraction and sunshine fraction was modelled by linear regression with observed cloud and sunshine from the BoM, while observed cloud fraction, sunshine fraction and incoming shortwave radiation data were used to determine the clear sky and cloud transmittance parameters.

Figure 1 shows examples of the SRAD SWS outputs for January and July in south-western Tasmania. A preliminary comparison of the SWH outputs for January and July with observed radiation data for 6 stations shows differences of less than 2% for 7 of the 12 comparisons and differences of 5% to 15% in the other 5. The causes of these differences are not yet known but differences in the period of record for parameterisation and validation is one possibility. Expanding the validation to include 12 months and 37 BoM stations should help to make this clearer.

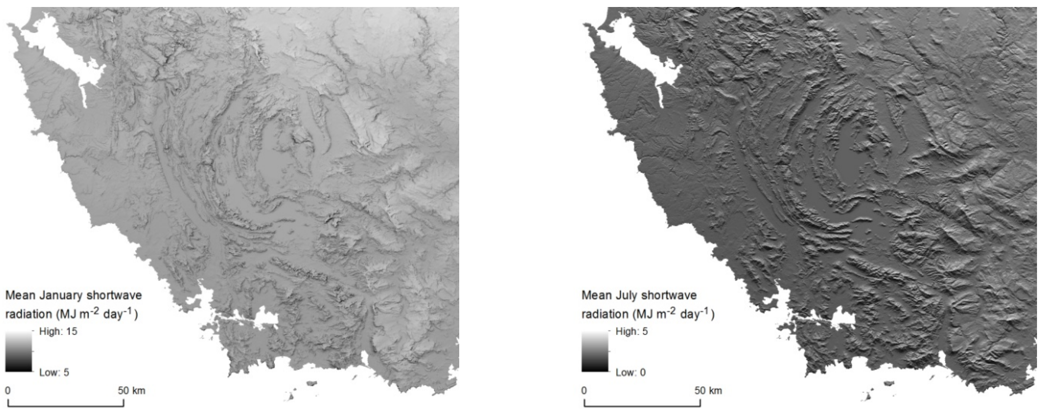

Figure 1. Modelled mean monthly total shortwave radiation on a sloping surface for January (left) and July (right) in south-western Tasmania. Note: these radiation values are from an earlier model run with less rigorous parameterization, and are an underestimate compared to observed values.

Keywords: *Solar radiation, Climate surfaces, Digital elevation model*

A Dynamic Habitat Mudflat Model for The Coorong, South Australia

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Abstract: The Coorong is a 2-3 km wide lagoon running parallel to the coast for approximately 100 km from the Murray Mouth in South Australia. It provides an important habitat for a wide range of bird species, and in particular has been listed as a Ramsar wetland due to its exceptional importance for migratory waterbirds. Using an extensive dataset of high resolution bathymetry data with the outputs of a CSIRO hydrodynamic model detailing hourly water level and salinity along the Coorong for given flow scenarios, we developed a dynamic habitat model for key bird species. The GIS-based model predicts the availability and viability of mudflats, defined as soft sediment areas that are either immersed or covered by no more than 12 cm of water, where most waterbird foraging occurs. Mudflat availability varies spatially and temporarily along the Coorong, and is influenced by tide, wind, rainfall and evaporation, some of which are dependent on the distance from the Murray Mouth and are affected by seasonal variation. The modelling of mudflats at different water levels suggests that an average water level of 0.12 m AHD gives the maximum average mudflat area across the majority of the Coorong.

We present a model that can be run for any given flow scenario over any time period for any site along the Coorong. However, this model can be easily modified for use in different environments where water level-habitat interactions are important. For the Coorong, it is important for managers to understand the influence of both water level and salinity on mudflat habitats as well as the aquatic habitats for fish, macrophyte and infauna. The spatial model developed for this study allows managers to readily quantify these habitats for specified flow scenarios, and supports informed decisions on the amount and frequency of barrage outflows from the Lower Lakes when excess water is available for environmental improvement and maintenance of the Coorong.

Keywords: *Habitat modelling, hydrodynamics, bird habitat, Coorong*

High Resolution DEMs from Unmanned Aerial Vehicles

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Abstract: Demand for high resolution DEMs in Australia seems to be insatiable. Released in 2012, the national 1 second resolution (30m) DEMs derived from SRTM provided a consistent high resolution continental coverage, though there are always applications that require better resolution. This is particularly the case where river channels that are less than one grid cell in width are involved. Examples where channel shape is important include hydrodynamic modeling and dam siting.

Previous papers by the authors at Modsim07 and Modsim09 described the need for more frequent survey with finer DEM resolution and the potential for cost effective methods such as Photosynth, which has since been joined by a number of commercial and open source competitors. A major obstacle in that method was the transformation from model to world coordinates. Recent developments in this area include the ability to work directly in world coordinates using air photos tagged with GPS camera position coordinates. Alongside software development has been the rapid development of low-cost and effective Unmanned Aerial Vehicles (UAVs) and cameras capable of obtaining high quality aerial photographs and video. The main advantages of these platforms are their relative low cost, less dependence on contractor schedules, and the flexibility to select the conditions and fly as frequently as necessary to achieve a desired result.

This paper describes the methods used in setting up a UAV and obtaining air photos, together with the use of freely available Structure from Motion (SFM) software to derive a high resolution DEM to supplement the national 1″ DEM. Comparisons of DEMs with the 1″ DEM show the effectiveness of relatively modest inputs.

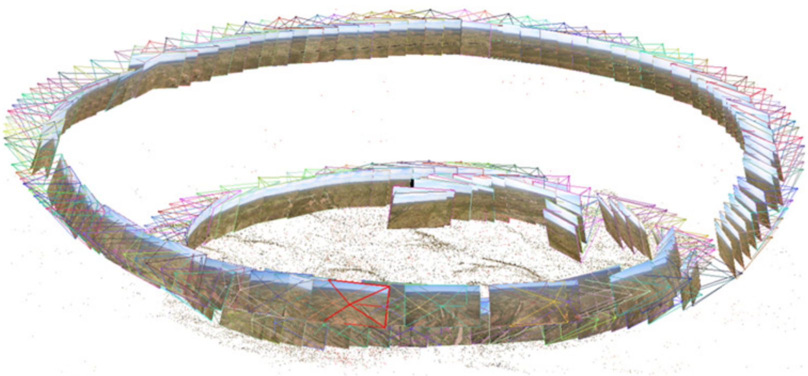

Figure 1. Airphoto camera positions and the derived point cloud which is subsequently interpolated at 2.5 m resolution.

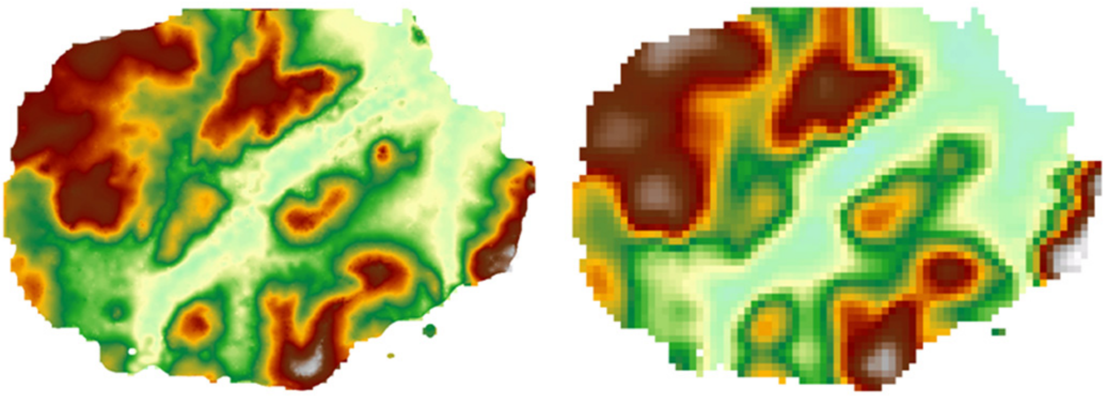

Figure 2. Comparison of 2.5m resolution Structure from Motion (left) and 1 second (30m) (right) DEMs

Keywords: *DEM, Structure from motion, Unmanned Aerial Vehicle*

Creating a flow-oriented modelling mesh using the stream function

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Abstract: Spatially distributed models of water flow on and just below the land surface require a mesh of spatial elements, which is usually formed as a regular mesh of squares, an irregular mesh of triangles or a mesh of curvilinear quadrilaterals aligned with the direction of flow. Each approach has its advantages; the attractions of the flow-aligned mesh are that the controlling equations are one-dimensional, which significantly simplifies the numerical methods, and that it can accurately represent the flow paths on the land surface with relatively few elements.

Flow-aligned meshes are typically created from contour lines using straight lines as approximations of the curved flow lines, leading to significant distortions in the directions and shapes of flow in some parts of the landscape. Contour lines are widely spaced in flatter areas leading to poorly structured meshes in valley floors where there is considerable hydrological complexity. The complex topological structure of the flow network also creates problems, although this has been largely solved by Moretti and Orlandini (2008, *Water Resources Research*, *44*, W05403).

The *Terrae* method has been developed to derive flow-aligned modelling meshes directly from grid digital elevation models by first constructing a stream function map for the surface. The stream function in this context has a constant value along a stream line and the difference in value between two stream lines is equal to the area between the lines. Once the stream function has been derived it can be used with elevation to create the flow-aligned mesh: each element in the mesh is bounded above and below by lines of constant elevation (contour lines) and on the left and right by lines of constant stream function (stream lines).

The stream function itself is constructed from the areas above and below each edge of every grid cell, using a novel flow accumulation method. The stream function is discontinuous along some lines joining saddles to peaks and sinks and the *Terrae* method resolves these discontinuities automatically, allowing the construction of coherent meshes in all parts of the landscape including depressions. Figure 1 illustrates the capabilities of the method in a low relief agricultural setting; elements of various sizes have been created to illustrate the flexibility of the method.

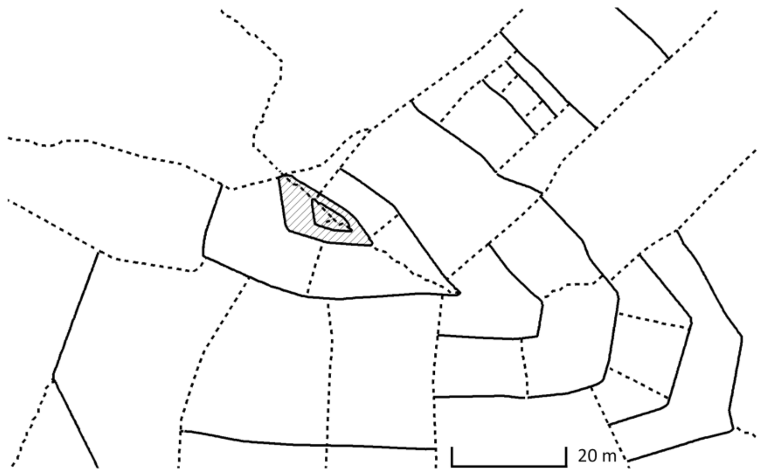

Figure 1 A flow-aligned mesh from a 1.3 m resolution DEM of an agricultural field, showing varying element sizes and elements constructed within a depression (hatched area). Contours are solid, stream lines are dashed.

Keywords: *Surface hydrology, Stream function, Digital elevation models*

Assessment of Spatial Models using Ground Point Data: Soil Matrix and Radiometric Approach

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Abstract: In this paper we present an assessment of the national airborne radiometrics model (NARM) using point based field data (soil samples) using landscape properties of topography, soils and geology. The Krui catchment, in north-west of the Hunter Valley NSW, Australia was used as the study site. Soils were sampled across two scales, and ^{40}K concentration of the soil samples determined. Relationships between the field ^{40}K and NARM ^{40}K were investigated using a digital elevation model, the national soil atlas model and the national geology model.

Our results showed that the NARM and field data are correlated and that this correlation extends across changing soil types and geology. A complex relationship with topographical features was also determined which needs further investigation.

Keywords: *Radiometric model, field testing, model assessment, potassium, soils*

FishTracker: A GIS toolbox for kernel density estimation of animal home ranges that accounts for transit times and hard boundaries

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Abstract: Understanding animal home ranges and other patterns of space utilisation is an important component of spatial ecology. It allows researchers to explore and explain site occupation and habitat preferences, and also interaction and avoidance behaviour. Conventional analyses of animal home ranges use points at which the animals are observed, sometimes weighted by the time difference between sequential observations. This creates an issue in that the analysis can assign undue weight to a sample point with a long time delay from the previous observation, as the full path from the preceding point is implicitly assigned to that point. Conventional analyses also do not take into account physical constraints such as boundaries (e.g. rivers, roads, cliffs) or the cost of traversing alternate possible paths between points, typically inferring a straight-line path between sequential samples. This conventional approach has obvious limitations, especially in constrained environments such as for fish in rivers and estuaries. These limitations can be attributed in large part to a lack of available software tools.

In this paper we describe a software tool we have developed that calculates kernel density estimates of occupation times by using the per-segment transit times along a path inferred using a cost surface that is constrained to remain between defined boundaries. To illustrate the functionality of the tool we use a data set of *Argyrosomus japonicus* (Mulloway) movements, an estuarine fish species, sampled from the Georges River estuary in Sydney, NSW. The approach is, however, generic and can be applied to any environment where animal movements are constrained, for example fragmented agricultural landscapes. The tool is written using the ESRI arcpy system, but is open source so can readily be ported to other GIS software packages.

Keywords: *telemetry, estuary, river, Vemco Positioning System, home range, space use, GIS, spatial ecology*

EXTENDED ABSTRACT ONLY

Combining satellite measurements and topographic downscaling to model net radiation and aridity in mountainous terrain

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Abstract: An index of aridity such as that developed by Budyko (1958) reflects the long term balance between rainfall and the net radiation across the landscape. Aridity influences vegetation structure, soil production and fire regimes, and is important for water and carbon dynamics at multiple spatial scales. Globally the effect of landscape aridity is apparent as a gradient in primary productivity going from rainforest to deserts. At local scales the effects are apparent as distinct shifts or gradients in microhabitats and catchment processes.

Net radiation in mountainous terrain can be modeled by combining point data with equations that incorporate the effects of elevation, surface geometry and atmospheric attenuation of incoming radiation. This modeling approach is suitable for representing radiation at a high spatial resolution, thus capturing small scale topographic effects on incoming radiation and temperature. Application of the topographic model to regional scale however is hampered by the complexity of representing the effects of cloud cover and landscape features on the partitioning of incoming radiation into diffuse and direct proportions. Larger scale patterns in radiation fluxes are more effectively captured in satellite-based measurements, which measure radiation at high temporal resolution over a large spatial extent, while capturing the variability introduced through temporal and spatial changes in atmospheric conditions due to cloud, snow, and geographic position.

This study proposes a method for scaling down satellite-derived data on incoming radiation in order to quantify net radiation and the Budyko Index of Aridity at high spatial resolution in complex terrain. The method utilizes satellite-based measures of incoming radiation obtained from the Australian Bureau of Meteorology (BoM) to provide the spatial coverage and long term data to characterize an average of the total incoming radiation across the state of Victoria in southeast Australia. These data were coupled with a topographic downscaling algorithm to produce estimates of net radiation and aridity at the resolution of a 20-m digital elevation model. The aim of the method is to incorporate topographic effects on net radiation while retaining information on the regional and seasonal trends captured in the long term data records on incoming radiation.

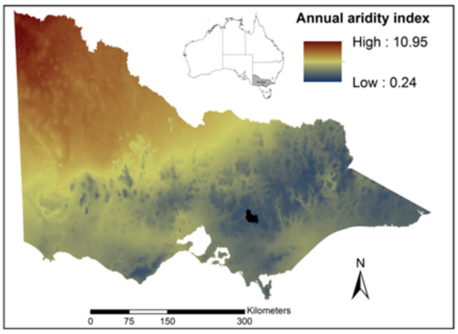

Figure 1. Budyko aridity index of Victoria at 20 m resolution.

Results show that annual precipitation (and cloud fraction) gradients drive the variability in aridity at large scales (10 – 100 km) while small scale (e.g. 1 km) topographic characteristics (e.g. slope aspect and slope angle) are the main drivers at local scales. The aridity index varied between 0.24 and 11 across the state of Victoria. Biomes range from temperate rainforest to shrub and open grassland. The effect of aridity on vegetation was apparent at local scales through systematic variations in tree-height along rainfall gradients and across aspects with different levels of exposure to solar radiation. Experiments are being carried out to test in more detail how topographic variation in aridity is driving differences in moisture dynamics in soil and litter. Differences in moisture dynamics due to topography can have large implications for soil formation, fire regimes and hillslope hydrology. The aim is to use the aridity as a predictor of how these processes vary across the landscape.

Keywords: *Landscape aridity, net radiation, topography, rainfall, soil moisture, water and carbon*

A Comparison of the Performance of Digital Elevation Model Pit Filling Algorithms for Hydrology

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Abstract: Digital elevation models (DEM) are widely used in hydrological applications for computing useful topographic parameters such as slope, flow direction, flow accumulation area and stream channel network. However, DEMs generally contain numerous topographic depressions which are real and/or artifactual. These depressions can take the form of single cells (pits) or contiguous areas in DEM (depressions). The problem with these pits and depressions is that they interrupt continuous flow paths in DEMs. To avoid these problems, all pits have to be rectified and create a depressionless DEM before calculating flow directions or any related topographic parameters.

Agency provided DEMs may be pit filled, but pits can also be generated while interpolating DEMs for changing grid spacing (e.g. LiDAR data). Therefore pit filling is an essential requirement for any hydrological study. A number of algorithms have been developed over the past few decades to treat pits in DEMs. With the availability of high resolution data, DEMs typically contain millions of cells which increase file sizes and computational effort. Therefore, efficiency of pit filling algorithms has to be taken into account when using such DEMs in hydrological applications.

In this paper, two of most widely used pit filling algorithms (Jenson and Domingue, 1988 and Planchon, 2001) are compared in terms of their performance and ability to extract topographical parameters. One arc second DEM derived from Shuttle Radar Topography Mission (SRTM) data was used in the study. Two study areas were used in the comparison. The first study area is comprised of three catchments located in Eastern Australia and they were used for evaluating topographic changes made by pit filling algorithms. The second study area is located in East coast and it was used to compare the performance of the two algorithms across a regional extent. According to the results, both algorithms behave similarly in modifying existing topography, but calculated flow accumulations and drainage networks were slightly different from each other. When the filled area was relatively small, both algorithms have resulted in similar flow paths. But in relatively large filled areas, they have resulted in unrealistic parallel flow paths significantly different from each other.

Both algorithms were implemented in the Python programming language to provide a common platform for comparison. Python is an interpreted language and the Cython tool has been recently developed to convert Python code to C code and allow it to be compiled. Cython was used to convert Python code to C extensions and the performance of both Python and Cython versions were evaluated. Time taken to execute pit filling algorithms on different sizes of DEMs was measured. The execution time of the Planchon algorithm showed a linear relationship with the size of the DEM while execution time of Jenson algorithm increased exponentially. Moreover, performance of both algorithms was evaluated for different resolutions, on a constant grid extent. The execution time of the Jenson algorithm increased with DEM resolution and showed a direct relationship to the total number of pits. However, execution time of Planchon algorithm remained almost constant regardless of the total number of pits. In Cython, both Jenson and Planchon algorithms showed significant improvement in execution time, relative to implementation in Python.

Keywords: *Pit filling, Digital elevation model, Python, Cython*

Spatiotemporal dynamics of surface water networks across a global biodiversity hotspot

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Abstract: The concept of habitat networks represents an important tool for landscape conservation and management at regional scales. However, few studies have quantified the naturally occurring spatiotemporal dynamics of networks, with the majority of studies assuming a fixed network structure through time. This can be problematic for aquatic systems which typically show high natural spatial and temporal variability. Here we derived large surface water networks using Landsat data from 1999-2011 over the Swan Coastal Plain (SCP), an area of 36,000km^2 that encompasses a global biodiversity hotspot in the Southwest of Australia and is subject to fast urban expansion, high rates of ground water extraction and a drying climate.

We generated an ensemble of 278 networks (corresponding to each remotely sensed time step during the 13 years of data) at three dispersal distances (500m, 1000m and 2000m) approximating the maximum dispersal distance of different water dependent organisms. We assessed the impact of climate variability on network topology metrics. We assessed the resilience of the network by quantifying the impact of removing wetland nodes on network topology according to four different strategies (removing random, smallest, least and most connected nodes). We varied the fraction of nodes removed from from 1 to 30% in 1% increments.

Results showed high temporal variability in network topology metrics. Network connectivity with different maximum dispersal distances varied by an order of magnitude. Number of nodes, number of edges and number of clusters show a highly dynamic seasonal pattern. A decline in connectivity over time can be noted at all three dispersal distances suggesting that the connectivity of the landscape has decresed from 1999 until 2011, with potential negative consequences for species with limited disperal capacity. Overall the trends in network topology metrics were similar between the dry and wet time steps when removing nodes according to the four different strategies.

Average precipitation in the previous two months explained approximately 70% of the variability in number of nodes. Future work will use downscaled global climate models to forecast changes in surface water network structure under various climate change scenarios and help prioritize surface water bodies in need of conservation for maintaining regional scale connectivity for different groups of organisms.

Keywords: *Surface water dynamics, complex networks, Swan Coastal Plain, Landsat, conservation*

Automated, web-based environment for daily fire risk assessment in New Caledonia

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Abstract: In New Caledonia, the increasing number, frequency, and extent of fires represent both a danger to human life and a threat to ecosystems conservation in an area considered to be a sanctuary of biodiversity.

A four-year study was carried out in the framework of the INC research project to better understand why fires start and to improve fire prevention. Based on satellite observations, a model was built to calculate the risk of fire ignition, together with a Bayesian network to link data on social, environmental, and climatological risk factors. The model and environmental, geological, and topographical data can be used to assess the impacts of fire on biodiversity and erosion.

The purpose of this paper is to present a tool designed to produce on-the-fly maps showing fire risk obtained. This web-based tool implements the model built during the research project and provides fire risk maps every day thanks to an automated recovery of climate data. The user only has to select the date of interest in order that the tool manages all the process of maps creation and display.

Open Geospatial Consortium (OGC) is an international organization in which governments, trade research, and non-profit structures collaborate to implement open standards related to services and geospatial content, as well as GIS data processing and sharing. The presented tool has been made with some standards specified by OGC (Geography Markup Language, Web Map Service), allowing it to be interoperable with other systems that implements OGC standards.

An online tool that exploits live results of the model and automated filling of a database enables identification of high fire risk sites. It then facilitates the task of land and environmental management by combining geographic data on location of water resources and roads that can be used to reach the potentially dangerous sites of fires.

Keywords: *Fire risk assessment, statistical model, interoperability, dynamic maps, OGC (Open Geospatial Consortium)*

Sensitivity of the BFAST algorithm to MODIS satellite and vegetation index

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Abstract: The Breaks for Additive Seasonal and Trend (BFAST) algorithm combines the additive decomposition of time series with abrupt change detection. It potentially allows for the effective use of the temporal detail available in satellite image time series for examining vegetation response patterns across regional extents, accounting for variation at the seasonal scale while detecting changes in the long term trends. While BFAST has been validated using NDVI time series (Verbesselt *et al.* 2010a), its sensitivity to different parameters and input data has not yet been assessed. Understanding the effects of the data source and type and the variation of the algorithm's user-defined parameters on the timing and number of abrupt changes it detects will allow it to be used more effectively. This study aims to assess the effects of the satellite used for data collection, the vegetation index (EVI or NDVI) and varying the value of a BFAST argument called the h parameter, which controls the potential number of trend breaks detected, on abrupt change detection for a study area in the Paroo region of north-western New South Wales, Australia.

Moderate Resolution Imaging Spectroradiometer (MODIS) EVI and NDVI time series were decomposed for 165 sample points chosen to include a range of land cover types in the study region. The effect of the MODIS satellite (Aqua or Terra) used to collect data was assessed by comparing the number of breaks detected and their timing between time series derived from each satellite. The effect of changing the h parameter was assessed by comparing the similarity in the length of time periods with a significant trend component slope between different values of h (1/3, 1/5 and 1/7).

The timing of detected breaks was affected by the satellite used to collect data, despite the visual similarity of Aqua and Terra time series. Greater certainty in the timing of breaks was achieved when using smaller values for the h parameter. Of the three factors tested, the vegetation index had the greatest impact on the timing and number of breaks in the long term trend detected by BFAST. The effect of the vegetation index was dependent upon the h parameter used, and the effects of both the h parameter and the satellite varied between EVI and NDVI. These results suggest a moderate sensitivity of the BFAST algorithm to all three of these factors, and also an interaction between them. This should be taken into consideration when using BFAST for long term vegetation change detection.

Keywords: *MODIS, EVI, NDVI, time series, change detection, vegetation dynamics*

A Naive Bayes classifier for modeling distributions of the common reed in Southern Finland

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Abstract: The field of species distribution and habitat suitability modeling has witnessed significant advancements in a number of aspects. One area that received much attention is the statistical underlying models in these studies. As data becoming bulky and prediction is often the goal of modeling, Data Mining and Machine Learning methods are becoming favorable in providing the underlying probability models for species distribution studies. Machine Learning encompasses a wide range of classification techniques, among others, with various capabilities. Although a number of techniques were presented and applied in species distribution modeling, many remain still untested. We here examine the potential of the Naive Bayes classification method, a widely and successfully applied technique in a number of fields, for modeling the common reed *Phragmites australis* distributions. We developed a Naive Bayes classifier to predict occurrences of *Phragmites australis* in a site on the Southern Finnish coast. We also tested the potential of the classifier to provide input to a cellular automaton for modeling the spread of *Phragmites australis*. The results suggests that the Naive Bayes classifier has significant potential in predicting species occurrences and providing transition rules for the dynamic modeling of species distributions.

Keywords: *Species distribution models, Phragmites australis, Machine Learning, Naive Bayes, cellular automata, Gulf of Finland*

The biogeography of New Zealand reptiles

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Background: New Zealand has been stratified into five biogeographic regions of varying degrees of biotic diversity and endemism, according to the inferred effects of historical climatic and geological processes and the modern-day distributions of species groups such as plants and insects. Although there has been considerable investigation into the historical origins of New Zealand reptiles, the distributions of New Zealand reptiles have received comparatively less attention. Do reptile distributions correspond to this broad-scale biogeographic regionalization? What is the relative influence of environmental turnover on reptile distributions and how might this vary at different spatial scales and locations?

Aim: To map the distribution of New Zealand reptiles by quantifying the fine-scale variation in reptile species turnover and endemism and assess these patterns in relation to the biogeographic regions that delineate New Zealand biota. To quantify the associated spatial turnover in environmental variables at different spatial scales and locations and to determine how the effects of environmental turnover on reptile distributions varies as a function of geographic scale and location. To characterise the reptile communities that occur in low and high turnover zones in relation to the historical geological and climatic processes that may have shaped New Zealand's flora and fauna.

Methods: We measured directional variation in reptile species turnover, endemism and spatial turnover in topography, climate and lithology using directional moving window analyses, rotated through 360°, which were applied to gridded cells containing georeferenced reptile occurrences and environmental variables. Generalised linear models were used to compare reptile turnover and endemism with environmental turnover surfaces at the different spatial scales, from national to local extents.

Results/Significance: Spatial turnover in environmental variables is more predictive of reptile turnover and endemism at local scales than at regional or national scales. Also, by stratifying biotic and environmental turnover into different geographic regions, marked contrasts appear in the nature of the biophysical associations, e.g. in the upper North Island, relationships between reptile turnover and environmental turnover are predominantly positive, whereas the opposite trend applies in the lower North Island. Low species turnover areas comprise <11% of New Zealand, yet they are populated with diverse reptile communities comprising >50% of reptile observations in 72 species. High species turnover areas are much more sparsely populated and show lower overall diversity. Low species turnover areas with large and diverse lizard populations did not consistently coincide with areas of high endemism. Low turnover areas occur throughout New Zealand, both in areas regarded as high diversity/endemism or potential glacial refugia, and also in areas characterised as biologically depauperate (e.g. mid-Canterbury, southern Wellington). In some locations, patterns of reptile turnover/endemism may reflect historical geological processes, for instance, higher reptile endemism in southern Wellington and the upper South Island could reflect the historical presence of a land-bridge connecting the two islands 6-2 mya.

Keywords: *Biogeographic regionalization, climate, endemism, reptiles, scale invariance, spatial turnover*

Modelling sea urchin feeding fronts

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Abstract: Feeding front formation by *Evechinus chloroticus* in New Zealand is the primary focus and motivation for our study. This endemic echinoid can be locally abundant, and has an important effect on the fauna of reefs. Dense feeding aggregations of sea urchins at kelp forest borders can lead to persistent losses of vegetated habitat, with attendant reductions in primary and secondary productivity, and flow-on effects to the wider ecosystem. Such events occur rarely, and their provenance is poorly understood.

We developed a mathematical model of front formation which posits successive capture and directional advance into stands owing to spatially-overlapping kelp frons, density-dependent capture success and reduced movement on capture. The movement of a sea urchin population is modelled as an integro-difference equation and the biomass of kelp is modelled as a difference equation and a function of the intrinsic rate of growth of kelp, the carrying capacity of kelp and a grazing function by urchins. The system of equations were solved numerically using MATLAB. Parameters for the model were obtained from local knowledge and by reviewing the literature. We ran and examined simulations for a number of scenarios and the model behaved well. A mechanism is offered for the propagation of the urchin feeding front into the kelp stand.

Keywords: *Sea urchins, feeding fronts, integro-difference equations, difference equation*

A physiological model for the marine cyanobacteria, *Trichodesmium*

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Abstract: Nitrogen fixation by the marine cyanobacterium, *Trichodesmium,* is believed to form a substantial component of the nitrogen budget of the Great Barrier Reef Lagoon. Here, we present a new, physiologically-based model to predict the distribution and growth of *Trichodesmium.* The model has been incorporated into a large-scale, process-based, three-dimensional hydrodynamic, sediment dynamic and biogeochemical model of the Great Barrier Reef Lagoon through eReefs, a major collaborative project that is developing near-real-time and forecasting models to inform management of this important environmental asset.

The model simulates the growth and respiration of *Trichodesmium* colonies, along with uptake of nutrients, fixation of atmospheric nitrogen, changes in cellular buoyancy, grazing by zooplankton and death associated with lysis by cyanophages. To facilitate improved simulation of nutrient dynamics as well as changes in carbohydrate ballasting (which affects buoyancy), the model allows variable intracellular C:N:P:Chlorophyll *a* ratios. Chlorophyll *a* accumulation and *Trichodesmium* growth depend on the intracellular availability of nutrients and fixed carbon. Carbon accumulation is a function of the spectrally resolved light environment, so that changes in light quality as well as light intensity may affect growth. As *Trichodesmium* colonies accumulate carbon, their buoyancy decreases, allowing the vertical movement of *Trichodesmium* through the water column to be simulated.

Particular attention is paid to simulating the nitrogen dynamics of *Trichodesmium*. Where sufficient ammonium is available in the water column, this is taken up preferentially, reflecting the lower energetic cost of this nitrogen source. When external ammonium concentrations are not sufficient to supply the cellular demand, *Trichodesmium* colonies take up nitrate. A novel model formulation is presented to simulate this preferential uptake dynamic without introducing an additional parameter. Only if the supply of dissolved inorganic nitrogen is insufficient do nitrogen fixation pathways become active in *Trichodesmium* cells. In this case, the growth rate of *Trichodesmium* is reduced in proportion to the energetic cost (in terms of ATP) of nitrogenase activity. With few exceptions, the values of parameters used in the model can be derived from direct measurements or theory.

Important processes not included in the model are also discussed; these include iron limitation of nitrogen fixation and the dynamics of surface scum. Unfortunately, it is not possible at this stage to include iron limitation, as iron inputs to the Great Barrier Reef Lagoon are not monitored; hence, iron is not included in the biogeochemical model. The dynamics of surface accumulations of buoyant *Trichodesmium* are an interesting problem in terms of physics, chemistry and biological processes, and may be considered in a future version of the model.

Keywords: *Physiological model, nitrogen fixation, eReefs*

Predictive modelling of five benthic habitats in shallow and turbid estuaries along the south-west coast of Australia

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Abstract: Identifying the spatial distribution and extent of benthic habitats in estuaries is important in managing our natural resources. As biotic habitats in estuaries can indicate the status of water quality, stabilize sediments, and capture nutrients from terrestrial runoff, modelling these habitats have important implications for local communities, state and federal governments. Although a number of remote-sensing habitat mapping methods have been successful in clear, shallow-water coastal environments and deeper marine environments, these methods fail in highly turbid and shallow estuarine environments. In this study, we used underwater video to estimate the percentage cover of five benthic habitat types (seagrasses (*Ruppia megacarpa*, *Halophila ovalis*, *Heterozostera australis*), green and red macroalgal morphologies, polychaete mounds (*Ficopomatacus enigmaticus*) and mussel clumps (*Mytilus edulis*)) in five estuaries on the south-west coast of Western Australia. Random Forest was used to model, predict and map their habitats across the estuaries based on the video data and spatially continuous environmental variables (seabed sediment composition (mud:sand, porosity, sorting, kurtosis), water quality (dissolved oxygen, salinity, temperature), and spatial (latitude, longitude, distance to coast, closest river, and closest marine entrance)). Random Forest is an ensemble, machine-learning method that is robust and able to handle non-linear relationships frequently encountered with ecological data. Random Forest is often used within terrestrial ecosystems but less so in marine ecosystems (e.g. predicting national coverage of seabed sediments, and substratum hardness for marine habitats). The results of this study show that Random Forest models performed well for predictions of benthic habitats, with 79–90% of variation explained by depth, latitude, longitude and water quality variables. This study confirms that Random Forest also has important applications in estuaries, with results refining existing baseline maps and highlighting the importance of biophysical processes driving plant and invertebrate species distribution. Underwater video and Random Forest modelling offer a valuable approach to mapping the spatial distribution of highly turbid benthic habitats in estuaries.

Keywords: *Benthic habitat, spatial modelling, random forest, estuaries, maps*

Assessing the sensitivity of nitrogen losses from cropping systems to different farm management practices

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Abstract: Nitrogen (N) lost from cropping systems has a major impact on the surrounding environment. An example of this impact is the contribution N losses from sugarcane production make to the declining health of ecosystems of the Great Barrier Reef (GBR), Australia. Governments have provided financial incentives for farmers to adopt 'improved' management practice to reduce N losses. However, there have been few experiments linking farm management with water quality in these environments, so there is uncertainty about what practices should receive the incentives. Nitrogen cycling can be accurately simulated in sugarcane production systems, so we undertook a simulation study to determine the sensitivity of N losses to farm management practices, across multiple soils and climates found in GBR catchments.

We used 'data mining' approach to determine the sensitivity, subjecting simulation outputs from a farming systems model to cluster and regression tree analyses. Cluster analysis was used to identify significant groupings within the data. The Partitioning Around Medoids (PAM) method was selected (in preference to the more commonly used method called k-means clustering) due to the robustness of PAM for isolating outliers and 'higher quality' clusters for the type of data we are analysing. Regression tree analysis was then used to identify/rank the most important determining factors for each output variable individually. Sugarcane yields and N losses were simulated with the APSIM (version 7.3) farming systems model for a combination of soils, meteorological stations and management systems relevant to four basins draining into the GBR, the Bundaberg, Burdekin, Mackay and Tully regions. Parameters for soil types were derived from previous experiments in each region and long-term historical climate data obtained for representative meteorological stations per region. The management practices represented in the simulations were different tillage, traffic (controlled or normal), fallow and N fertiliser practices. Fertiliser practices included a range of application rates and split applications. Irrigation management (timing and amount applied) were also represented in the Burdekin. Outputs included N lost in runoff, leaching below the root-zone, denitrification, the total N losses via all three pathways, and sugarcane yield.

In all regions, the amount of N fertiliser applied was the most influential factor determining total N losses. The second most influential factor was rainfall in the Bundaberg, Mackay and Tully regions. As expected, rainfall was not influential for the irrigated crops of the Burdekin region. Although farmers cannot influence the amount of rain they receive the results suggest there could be scope for adapting management approaches and/or schedules to the projected climate in the forthcoming season if skillful projections are available. For the specific N loss pathways (as opposed to total N losses), factors other than N rate became influential. N in runoff was sensitive to tillage and controlled traffic management, as well as irrigation in the Burdekin region. Soil type and climate were also influential. N lost through deep drainage or denitrification was most sensitive to N fertiliser application rate. The effect of splitting N fertiliser did not have a significant effect on N lost through any pathway. This could be because the N rates simulated generally excluded rates low enough to cause crop N stress, and there was no potential for splitting to increase crop N availability. Splitting maybe significant at lower N rates. Cane yield was highly influenced by N fertiliser at Bundaberg, but not in any other region. This lack of response can also be explained by the exclusion of low N rates from this study. Controlled traffic was the other management factor influencing yields, having most influence in the Bundaberg simulations. Rain and soil type also influenced yields, but their influence varied between regions.

The results for N losses show that the amount of N fertiliser applied determined the total loss of N from fields, with the partitioning of this loss between the different possible loss pathways (runoff, leaching or denitrification) determined by climate, soil type and other management practices. More specifically, the 'other' management practices are tillage, controlled traffic and, where relevant, irrigation, and these mainly affected N lost via runoff. Reduced N application rates, with reduced/zero tillage and controlled traffic will be the most effective management practice that farmers could adopt to reduce N losses to the GBR.

Keywords: *APSIM, cluster analysis, Great Barrier Reef, regression tree analysis, water quality*

Sensitivity analysis to investigate the factors controlling the effectiveness of a nitrification inhibitor in the soil

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Abstract: Nitrification inhibitors have been proposed as an option to mitigate nitrogen (N) losses from farmland. One of these inhibitors, dicyandiamide (DCD), has been shown to significantly reduce N leaching and N_2O emissions from nitrogen enriched soils with no adverse effects to the soil environment. However, the effectiveness of DCD in reducing N losses has been shown to be quite variable. We postulate this variability can be linked to the persistence of DCD in the soil layers where ammonium is located. DCD in soils will be subject to biodegradation and so the persistence of DCD in soils should be inversely proportional to microbial activity, for which temperature is a major driver. Furthermore, DCD is a neutral-charge compound and so should be highly mobile in soils and prone to leaching in direct proportion to rainfall. Thus, after application, the distribution of DCD in the soil profile over time can be affected by temperature, rainfall and the soil's drainage characteristics. We employed the simulation model APSIM with a recently-developed DCD module to analyse how the environmental conditions affect the processes governing the persistence of DCD in soils. The analyses involve data from simulations of typical pasture land in different locations across New Zealand with representative rainfall and temperature regimes and soil types. The simulations considered the application of DCD at different rates and in different seasons, over a 20 years period. Using sensitivity analysis techniques, we studied which processes play the greatest role in the disappearance of DCD. This led to recommendations for experimental protocols, including soil sampling, and data analysis which can be used to discern between leaching and degradation.

The persistence of DCD was studied using the solutes' apparent half-life, that is, the time taken for the concentration of the solute to decrease to half of its initial concentration. We use the adjective 'apparent' because the reduction in concentration is a result of a combination of degradation and leaching rather than degradation alone. The results from the simulations with DCD were compared with those from simulations with the application of an inert tracer in which the apparent half-life is affected by leaching alone. Differences in the apparent persistence of DCD and tracer from the soil's top 20 cm layer were used to infer the relative effects of degradation and leaching. The results showed large variability for the values of apparent half-life of both solutes, but the variability was considerably smaller for DCD than for the tracer. The month of application and location (weather) were the two major factors driving the variations in apparent half-life of both solutes, with soil-type and some of the interactions between factors being secondary. However the order of relevance for the factors was different for DCD than for the tracer. Overall the influence of month of application in the apparent half-life of DCD was quite small, whereas it was the most important factor for the disappearance of the tracer. The difference between the apparent half-lives of the two solutes can be used to infer the effect of degradation on DCD persistence; the results show, therefore, that the month of application is very important for determining DCD degradation. The relative effects of leaching and degradation follow a clear seasonal pattern, in summer degradation is the major factor and leaching is of lesser importance, but in winter leaching is much more important than degradation. This offset seasonality for the two processes results in the low overall seasonality for the apparent half-life of DCD. It also emphasizes the challenge of distinguishing the relative importance of leaching and degradation for DCD persistence in the soil. To better determine the causes of variation in residence time of DCD, and thus its effectiveness, experiments should use a tracer applied alongside DCD.

Keywords: *Nitrogen losses, Water quality, Soil processes, DCD, Sensitivity analysis, APSIM simulation*

Bayesian hierarchical modeling of soil carbon dynamics

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Abstract: Carbon accounting is becoming increasingly important as countries tackle the difficult task of mitigating climate change. One important pool of sequestered carbon is soil and there is potential for farmers to adopt management practices that help to sequester atmospheric carbon there. A number of models have been developed to track the masses of carbon sequestered in agricultural systems, for example RothC, Century, and FullCAM. Whilst very useful, these models are deterministic by design and so suffer from an obvious deficiency: they are unable to report on the certainty about the predicted masses of carbon sequestered under a given management scenario.

This talk introduces Bayesian Hierarchical Modelling (BHM) as a framework within which we can embed process models, such as those used in soil carbon modelling, to obtain outputs that provide an assessment of our certainty/uncertainty. We introduce this idea using a single pool carbon model built using a soil carbon dataset from Tarlee, South Australia as a proof of concept. This carbon data together with annual observations on crop productivity and prior knowledge of the parameters that drive change in carbon enable on to follow such a modeling framework.

Fitting a BHM often involves the use of Markov Chain Monte Carlo simulation through the use of Gibbs sampling and Metropolis-Hastings steps. We have demonstrated that such an approach works here, (e.g. see Figure 1 which highlights uncertainty in the underlying soil carbon process) but we have also demonstrated the use of Particle marginal Metropolis-Hastings through the LibBi modeling language. Such an approach is better suited to implementing a more complete soil carbon model such as RothC or FullCAM for two reasons. It enables one to capture the model complexity using straight forward declarations of the model form and the computational complexities of the model are eased as LibBi builds scalable code that takes advantage of the available computing resources.

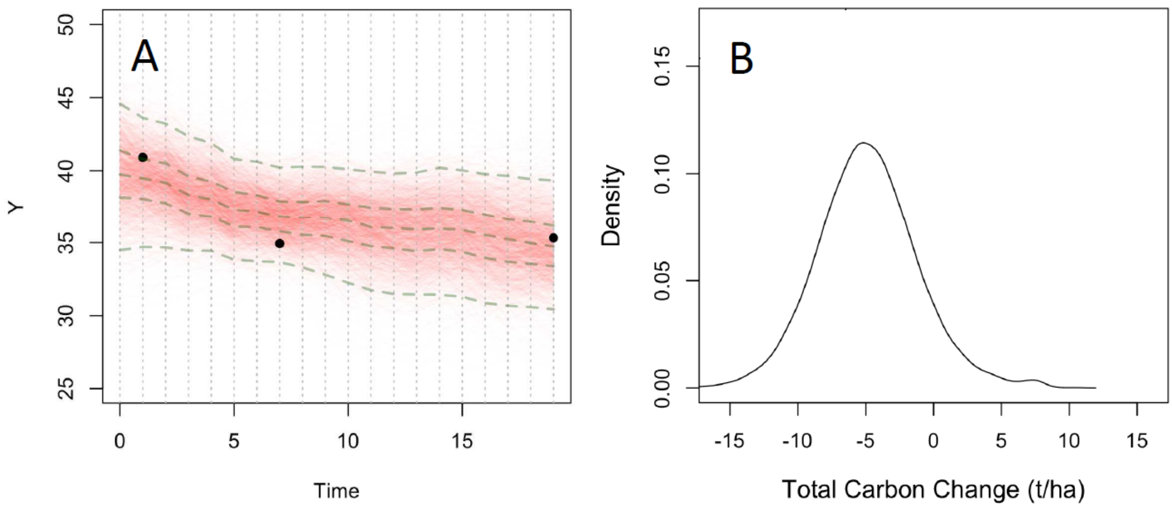

Figure 1. A: Soil carbon measurements (black dots), simulated soil carbon process trajectories (red lines) together with quantiles (green lines) plotted against time. B: Change in soil carbon over 20 year period at Tarlee, South Australia.

Keywords: *Physical statistical modelling, particle filters, soil carbon*

Sensitivity analysis of SWAT model in the Yarra River catchment

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Abstract: Catchment-scale hydrologic and diffuse source pollution models simulating a catchment are useful analysis tools to understand problems and find solutions through simulation of BMPs for particular catchment and agronomic settings. However, developing reliable catchment model and validating them on real-world catchment with monitored data is challenging. In this regard, model calibration and uncertainty analysis help to evaluate the ability of the model to sufficiently predict streamflow and constituent yields for specific applications. Complex physics-based distributed models contain many parameters that can complicate calibration process. In addition, the model when includes multi-variable at multi-site with multi-objective functions introduces more complexity to the calibration process. Over-parameterization is a well-known problem in such distributed model. Sensitivity analysis methods reducing the number of parameters to be adjusted during calibration are important for simplifying the use of these models. The objective of this paper is to perform a sensitivity analysis for multiple variables (streamflow, sediment and nutrients) at three sites on a SWAT model developed in the agricultural part of the Yarra River catchment, Victoria (Australia) so that the model can be calibrated efficiently for water quality analysis purposes.

SWAT is a continuous physics-based distributed model that operates on a daily time-step. The SWAT model requires the following data types: digital elevation model (DEM), land use, soil, land use management, daily climate, streamflow and water quality data. Australian catchments are data-rich in terms of hydroclimatic data, but data-poor especially for water quality and land use management. For this study, all the data were collected from local organizations except DEM. Water quality and land use management data were most sparse. All input files for the model were organized and assembled following the guidelines of ArcSWAT interface of the SWAT 2005 version. The study area was delineated into 51 sub-catchments and 431 hydrological response units (HRU), which are unique combinations of land use, soil type and slope. The main methods used in modeling the hydrologic processes in SWAT were curve number method for runoff estimating, Penman-Monteith method for PET and Muskingum method for channel routing.

SWAT has an embedded automatic sensitivity, and calibration and uncertainty analysis tool. The sensitivity analysis method is a combination of Latin-Hypercube and One-factor-At-a-Time (LH-OAT) sampling that allows a global sensitivity analysis for a long list of parameters with only a limited number of model runs. SWAT has 26 streamflow, 6 sediment and 9 nutrient parameters. The LH-OAT sensitivity analysis was applied for streamflow (Q), Total Nitrogen (TN), Total Phosphorus (TP) and Total Suspended Solid (TSS) output variables at three sites in the study area for 1998-2008 periods.

The LH-OAT sensitivity analysis provides a simple and quick way to assess parameter sensitivity for multiple variables across the study area. The output variables found to be most sensitive to 15 hydrologic parameters, and 13 sediment and nutrients parameters in the SWAT model. The results show that the hydrologic parameters dominate the highest parameter ranks. The results also show that water quality variables are potentially capable of contributing to the identification of water quantity parameters within the SWAT model, and a single parameter is correlated to multiple variables. Moreover, there were clear differences in ranking of a parameter among the three sites. This result has evidenced how the parameter importance depends on land use, topography and soil types, meaning that a generalization within a catchment is limited. Hence, justify the importance of multi-site parameterization

Keywords: *Sensitivity analysis, SWAT, Latin-Hypercube and One-factor-At-a-Time (LH-OAT) sampling, Yarra River catchment, Australia*

Meta-modelling the NZ-DNDC model for nitrous oxide emissions from grazed pastures

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Abstract: Nitrous oxide (N_2O) emissions from agricultural soils are a major greenhouse gas source in New Zealand, accounting for 13.9% of total greenhouse gas emissions. N_2O is produced by microbial transformation of N-compounds in the soil and emissions have a high degree of spatial and temporal variability. N_2O emissions are frequently reported in terms of an emissions factor (EF), which is the fraction of applied N that is lost as N_2O. DNDC is a process-based biogeochemical model that simulates greenhouse gas fluxes from agricultural soils. A New Zealand specific version (NZ-DNDC) has previously been developed and used to estimate N_2O emissions at site and regional scale.

However, running the model at regional scale is computationally expensive if a large number of sub-units are used. Increasing the size of the sub-units increases the variability of soil parameters within each sub-unit and can lead to high uncertainties in the modelled results. Frequently there are high uncertainties in available soil data, which also lead to high uncertainties in modelled results. A simplified model may have fewer data requirements and be faster to run, making it easier to simulate the impacts of land-use and/or climate change scenarios.

In this study we performed regression analyses on the output of a large number (almost 1.4 million) of 1-year NZ-DNDC simulations covering the range of soil parameters and climate conditions occurring in New Zealand for three representative grazed pasture systems. The aim of this exercise was to determine which input parameters have the greatest influence on N_2O EFs and whether a simplified version of the model could be developed.

Regression analyses were performed using R version 2.12.1. Due to memory restrictions 100,000 randomly selected simulations were used for the model development with the remaining simulations reserved for model validation. Stepwise regression was used to select the best set of predictors for N_2O EF (based on Akaike (1974) Information Criterion, AIC) from soil organic carbon (SOC), pH, bulk density, drainage, N applied, mean annual temperature, maximum temperature, minimum temperature, total rainfall, number of rain days, as well as interaction terms for SOC with drainage, total rain, N applied and rain days and drainage with N applied, annual rainfall, and number of rain days. Using backwards selection only the interaction between drainage and applied N was dropped, leaving a model that explained 74.0% of the variability. Forward selection was also used to examine models with fewer explanatory variables. Table 1 shows that the model containing only SOC and texture class still explained 60.7% of the variability. Additional parameters produce only small improvements in the variability explained.

Table 1. Contribution of parameters to explaining the variability in simulated nitrous oxide EF

Model	Model df	R^2	Additional variability explained
+SOC	1	0.457	45.7%
+Texture class	11	0.607	15.0%
+ Bulk density	12	0.644	3.7%
+ Drainage class	13	0.673	3.0%
+Rain days	14	0.681	0.7%

Regression analysis can be used to develop simplifications of process-based models that are faster to run and have fewer input data requirements. Further analyses and validation will be given in the presentation.

Keywords: *Nitrous oxide, greenhouse gases, NZ-DNDC, meta-model*

Uncertainty in modelled soil organic carbon changes under various cropping systems in Australian cropland

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Abstract: Agricultural soils have been suggested to sequester soil organic carbon (SOC) through adopting conservation agricultural practices such as residue retention, no-till and increasing cropping complexity. At regional or continental scales, however, it is a significant challenge to quantify the changes in SOC stock and the corresponding uncertainty associated with variation of cropping systems and environmental conditions at high spatiotemporal resolution. Here, our aim was to predict changes in SOC stock after adopting different cropping systems under optimal management for sequestering soil carbon (i.e., no nutrient deficiency and 100% residue retention) and quantify the relevant uncertainties at regional scale. Using the farming systems model APSIM, we simulated changes in SOC stocks for a 20-year period from 1990 to 2010 under a total of 59 cropping systems at 613 references sites across the Australian cereal-growing regions. These cropping systems were identified based on GRDC agro-ecological zones through expert consultation. To further understand the effects of cropping system in terms of carbon input on SOC dynamics, those cropping systems were divided into three categories to represent low-, medium- and high-input cropping systems in terms of carbon input. The simulation results indicated that, on average, the Australian agricultural soils could gain 0.19 t C ha^{-1} yr^{-1} under optimal management. However, the predicted change in SOC stocks had high variability among the three carbon-input categories. Generally, cropping systems with higher carbon input had higher efficiency for reducing SOC losses or enhancing SOC gains compared to lower carbon-input systems. For the same category of cropping system, its ability to reduce SOC losses or enhance SOC gains varied across difference GRDC zones. For example, in Qld Central zone where has higher temperature, the SOC experienced loss regardless of cropping system. In SA Vic High Rainfall zone where has lower temperature and higher rainfall, the SOC showed increase. This result indicated the importance of local soil and climate conditions to regulate the SOC dynamics under different cropping systems.

A Monte Carlo approach was applied to assess the uncertainty induced by cropping system and scaling of point results to GRDC zone. Averaged across all representative cropping systems, the predicted mean SOC change was –0.1 t C ha^{-1} yr^{-1} with the 95% confidence interval ranging from –0.22 to +0.007 t C ha^{-1} yr^{-1} in Qld Central. In NSW NW/Qld SW, the predicted SOC change was zero with the 95% confidence interval ranging from –0.05 to +0.05 t C ha^{-1} yr^{-1}. In other zones, the predicted SOC change was positive. In Vic High Rainfall zones, the SOC change reached the greatest increase of +0.44 t C ha^{-1} yr^{-1} with the 95% confidence interval ranging from +0.22 to +0.66 t C ha^{-1} yr^{-1}. In Western Australia, the predicted SOC change was generally positive across all representative cropping systems. There was significant difference between different cropping system categories. In general, cropping systems with higher carbon input could reduce the SOC losses or enhance SOC gains compared to cropping systems with lower carbon input. In three zones of Western Australia (WA Northern, WA Eastern and WA Central), however, the predicted average SOC change under high-input cropping systems was lower than that under medium-input cropping systems. We further calculated the contribution of cropping systems and scaling to overall uncertainty. The simulation indicated that the variability of cropping system accounted for ~30% of the overall uncertainty. The greatest contribution of cropping system change to uncertainty in simulated SOC (>60%) was observed in three GRDC zones, i.e., NSW NW/Qld SW, NSW NW/Qld SE, and WA Northern. Our results suggested that the uncertainty in scaling of point results to regional scale is dominant in the overall uncertainty. More detailed soil databases and information on cropping systems are needed for reliable prediction of SOC dynamics in agricultural soils at regional scale.

Keywords: *APSIM, carbon input, crop sequence, Monte Carlo simulation, soil carbon change, uncertainty analysis*

Bayesian Analysis of Computer Code Outputs (BACCO) applied to an agent-based model

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Abstract: Agent-based models are often large and complex simulations with significant data requirements. The complexity of the model may also lead to problems in communicating the model, validating the model behaviour or conducting sensitivity analysis. In order to address the importance of critical interpretation of agent-based models in an efficient manner, we introduce a novel methodology with which to analyze the sensitivity of a complex Agent-based model, Bayesian Analysis of Computer Code Outputs (BACCO) using the freely available software tool GEM-SA. BACCO constructs an emulator of the model in order to provide a rapid and thorough sensitivity analysis. With BACCO sensitivity analysis, the number of code runs can be dramatically reduced compared with traditional Monte Carlo (MC) sensitivity analysis, making it much more widely applicable in practice.

To construct the emulator, for the prior output expectation we use an additive linear function of each of the inputs of interest. A covariance function is also required, to characterize smoothness of the output. When the prior distribution is updated via Bayes' Theorem with the observed input and output training data, we obtain a posterior distribution whose mean function exactly interpolates the true code output at the observed runs with variance zero. The variance (i.e. uncertainty) of an untried output $f(x)$ increases as x moves further from the training inputs. This posterior distribution is the emulator.

In the Skylark model case study we present, it became clear the input parameter 'nest leaving weight threshold' was by far the most influential of the inputs considered, however the direction of the relationship with the output of population size was counterintuitive. This led us to further explore the interaction between parameters in the model to interpret the result. Overall, our experience highlights the importance of the ability to rapidly identify input parameters in the model that require more rigorous parameterization, as some parameters are highly sensitive and can produce spurious results when varied even a small amount. Transparency is very important in modeling. Methods such as BACCO encourage modelers to think about the meaning of input parameters, plausible ranges and the consequences of variations and uncertainty, rather than hiding them away inside a `black box'. They can also help to build trust in the model outputs that may be more difficult to gain from presenting more complex raw outputs.

This work was recently published in Environmental Modelling and Software http://dx.doi.org/10.1016/j.envsoft.2012.08.006, and the presentation at Modsim will give an overview of the technical aspects.

Keywords: *Agent-based model, ALMaSS, Land use policy, Sensitivity analysis, Set-aside removal, Skylarks, Emulator, Meta-model, Uncertainty, BACCO*

The use of generalised linear uncertainty estimation (GLUE) to assign initialisation values to conceptual soil organic matter pools in APSIM

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Abstract: There is a growing need for systems models to address the implications of agricultural management decisions on nutrient dynamics (including leaching and gaseous losses) and soil carbon storage. As a result, greater emphasis and scrutiny is being placed upon the soil components within these models. Many models simulate the cycling of soil organic matter (SOM). However, it is demanding to be able to incorporate all of the complexities of a typical set of soil – plant – management interactions. The Agricultural Production Systems sIMulator (APSIM) is a systems model that simulates a range of plant, animal, soil, climate and management interactions. Many SOM models, including the published/release version SoilN in APSIM used in this study, are based on conceptual SOM pools. Therefore, while values for total SOM can be used to initialise the sum of the conceptual pools, the individual pools cannot be initialised with measured values. In the majority of studies ‘expert opinion’ is used to distribute SOM between the conceptual pools, however this approach is subjective and open to criticism. The initialisation of these conceptual SOM pools in models can be important drivers of the results obtained over the short to medium term.

This work used a generalised linear uncertainty estimation (GLUE) approach as a formal and rigorous framework to estimate the optimum initial set up of SOM pools, by inferring their values from their combined behaviour (i.e. total SOM) through time, compared to observed data. The observed data was taken from a medium-term (12 years) field experiment established in 2000 at Lincoln, Canterbury, New Zealand. The site had previously been under permanent grazed pasture. The experiment included an uncultivated chemical fallow treatment, which is maintained plant-free using herbicides, and a permanent pasture treatment. These two treatments represented two contrasting SOM inputs, from none to a supply fresh organic material throughout the year.

The GLUE framework used a non-statistical Monte Carlo procedure with threshold screening. Initial ranges and distributions of parameters were determined *a priori* and inferred from the literature or the dataset itself. The values of parameters were varied within the ranges, according to the distributions, to give a set of initialisations with which APSIM was run. The model outputs were then compared to the observed data using a number of likelihood measures, determining whether a particular initialisation was considered ‘behavioural’.

The analysis demonstrated that widely different initial distributions between the conceptual SOM pools could simulate the observed behaviour of total SOM over the medium-term. This is a demonstration of the equifinality principle; in large complex simulation models more one than initialisation can give you the same or equally ‘good’ result. Clearly not all these initial values can be ‘correct’ and, it is hypothesised that if extended beyond the duration of the dataset, the model outputs may ultimately lead to differing points. The implications for uncertainty in the initialisation of conceptual SOM pools in systems models highlight the need for testing of these models on long term data, and provide further weight to the need to move to models which include measurable, as opposed to conceptual, pools.

Keywords: *SOM modelling, GLUE, APSIM, systems model*

Does soil water model complexity affect the sensitivity of drainage and leaching to variation in soil hydraulic parameters?

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Abstract: Soil hydraulic parameters are a major source of uncertainty when modelling drainage and leaching at the catchment or regional scale. When faced with high uncertainty in input parameters it is often recommended that simpler models be used, implicitly assuming that simpler models are less sensitive to uncertainty in the input data. However this assumption is seldom tested. We tested the sensitivity of the outputs from two soil water models of differing complexity to variation in soil parameter data. The complex model was SWIM3 and the simpler soil model was SoilWat. SWIM3 uses the Richards equation, a mechanistic representation of the non-linear reduction in hydraulic conductivity as soil dries, with the convection-dispersion equation for solute movement. SoilWat predicts drainage as first-order equation with a mass flow calculation of solute movement. Both these models were used to predict drainage and nitrate leaching below the root-zone in a grazed pasture within the APSIM simulation platform. Most inputs and simulation settings were constant across the two soil models.

Simulations were run for a pasture system under dryland, fixed-interval or dynamically-scheduled irrigation. Urine depositions of 250 (dryland, sheep) or 500 kg N /ha (irrigated, cattle) in March or September were imposed every three years to mimic the nutrient return under grazing. The simulations were run with weather data from Canterbury, New Zealand for 1993 to 2008 inclusive. Two hundred variants of a typically light Canterbury soil with three horizons were simulated. The soil parameters varied were bulk density and the water contents at air dry, 15-bars, drained upper limit and saturation. In addition SWIM3 used the saturated hydraulic conductivity (K_s), which was log-normally distributed, while SoilWat used a parameter called SWCon, which was related to K_s but was normally distributed. The outputs considered here were the 16-year annual average amounts of drainage (mm /yr) and nitrogen leached (kg N /ha /yr). The sensitivity was normalised against the median for the model and output. No calibration between models was carried out.

The choice of soil model affected the amount of drainage, particularly under dryland conditions, and leaching (Figure 1). Under dryland conditions the soil model had little effect on variability of drainage – there was approximately equal sensitivity of drainage to variation in soil parameters for the two soil models. Under irrigated conditions, SoilWat showed greater sensitivity to soil parameters than SWIM3 and this was particularly true when irrigation amount was fixed rather than dynamically scheduled. For these simulations the inter-quartile range of the normalised drainage for SoilWat was about double that from SWIM3. There was little difference in the sensitivity of leaching to variations in soil hydraulic parameters between the two soil models.

These initial results suggest that for the simulation conditions here the more complex soil model has generally equal or lesser sensitivity to uncertainty in the soil hydraulic parameters than the simpler model. This was an initial study with a single soil and so should be expanded to include a range of soil textures and permeabilities as well as different farming systems.

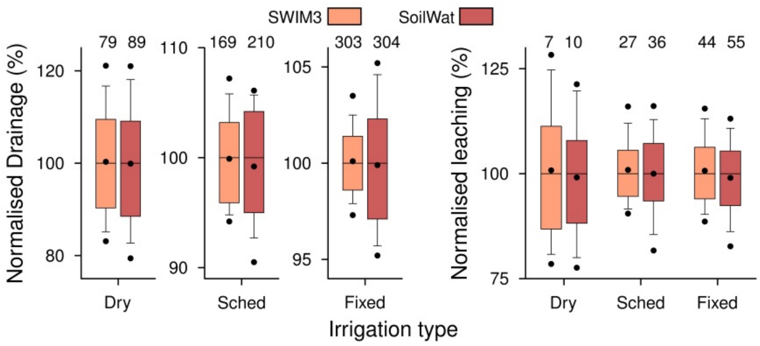

Figure 1. Variation in drainage and leaching normalised against the median value under the three irrigation types for the two different soil models. Median values are shown above each set of simulations.

Keywords: *Sensitivity analysis, Simulation modelling, APSIM, SWIM, SoilWat*

The benefits of sensitivity analysis in an interdisciplinary environment, a case study: the Ecomeristem model

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Abstract: The models developed by scientists are more and more complex. Indeed, these models are composed of a large number of sub-models than can interact with other models and sub-models. These processes and interactions define non linear and non derivable outputs. This is why we need to analyze the properties of such models if we want to qualitatively validate them, infer new knowledge or evaluate the impact of an event on the system. In this context, the use of sensitivity analysis seems fundamental and is a tool that allows having a better understanding of our models. This paper presents why and how we use sensitivity analysis on the Ecomeristem model. Ecomeristem is a whole-plant, deterministic, dynamic, radiation and temperature-driven crop model within the category of Functional Structural Plant Modeling. It includes also soil and plant water balance (to study, for instance, drought stress) modules. The main distinguishing mark of this model is its capability to simulate competition for assimilates (supply) among growing organs (demand). The plant is simulated as an average individual of a population forming a canopy. Plant organogenetic and morphogenetic processes are driven by incremental carbon assimilate source and sink depending on genotypic parameters and environmental conditions. This model has been developed in an interdisciplinary environment and is a result of collaborations and works between scientists involved in ecophysiology, genetics, computer science, and applied mathematics. For this study, we used the extended Fourier Amplitude Sensitivity Test (called `fast99` and comes from the `sensitivity` R package). This method allows the estimation of first order and total Sobol' indices for all the factors. One of the main advantage of this method is that if n is the sample size and p the number of factors, the number of simulations needed to produce the sensitivity indices is: $n \times p$. Using `fast99` we carried out a large number of sensitivity analysis. These results help us to build and improve the ecomeristem model. They help to have a better understanding of the biological processes we modeled and allow to note that they processes behave properly (*e.g* the variation of input parameters implies the variation of the observed output variable). Moreover, in a computer science point of view, by performing a large number of simulation, and consequently, a large number of simulation trajectory, the combination of input parameters values proposed by `fast99` allows to exhibit remaining bugs within the model. Due to the large number of interactions between the models, this work would be very hard to do so if scientists have to imagine these combinations of parameters.

For instance, we carried out a sensitivity analysis of shoot dry weight simulations to model plant parameters under drought. Plasto, defining the constitutive leaf appearance rate, showed the highest sensitivity indices, prior to other constitutive sink related and drought response parameters. However, Epsib, light conversion efficiency, showed sensitivity indices similar to Plasto (around 0.55) with even a slightly higher main effect. The impact of drought response parameters was generally low excepted powerFTSW (sensitivity of carbon assimilation to drought) showing sensitivity index of almost 0.2 and being thus the third most influent parameter.

Keywords: *Functional Structural Plant Models, Plant biology, Ecophysiology, Sensitivity Analysis, Modeling, Simulation*

Integrating two process-based models for assessing dairy system management impacts on N losses

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Abstract: Estimating N losses via different pathways and forms is important to inform management and policy changes that have the potential to reduce environmental impacts. No currently available process-based model has sufficient complexity to simulate Australian dairy farming systems and their contribution to N exports in all pathways and forms. In this study, the DairyMod and Howleaky models were combined to estimate N losses from dairy systems. DairyMod simulates the top-soil and bottom-soil N concentration time series, and vegetation cover time series, to import into Howleaky. Within Howleaky a newly developed N-module was used to estimate the N losses. Dissolved N (DN) loss in runoff is calculated as:

$$DN\,conc.in\,runoff\,(mg/l) = DN_{soil} \times k \times \left[1 - \exp(-cv \times runoff)\right] \quad (1)$$

$$DN\,load\,(kg/ha) = DNconc.in\,runoff \times runoff\,(mm) \quad (2)$$

where DN_{soil} (mg N/kg) is nitrate concentration in the surface soil layer contributing to runoff which was an output from DairyMod simulations in this case; *k* (unit less) is a parameter that describes the mixing of soil N with runoff water and *cv* (/mm) is the response curvature. Particulate N (PN) loss in runoff is calculated as:

$$PN\,load = E \times TN_{soil} \times NER_{soil} \times 10^{-6} \quad (3)$$

where *PN* = particulate nitrogen export (kg ha^{-1}); *E* = potential field gross erosion (kg ha^{-1}) calculated by the Howleaky model; TN_{soil} = total nitrogen content of topsoil (mg kg^{-1}); NER_{soil} = soil Nitrogen Enrichment Ratio. Nitrate leaching is estimated as:

$$Nitrate\ conc.in\ soil\ water(mg/l) = BN_{soil} / Total\ soilwater \quad (4)$$

$$Nitrate\,leaching\,(kg\_N/ha) = Nitrate\,conc.in\,soil\,water(mg/l) \times D \times LE \quad (5)$$

where BN_{soil} (kg N/ha) is the monthly nitrate content in the soil layer contributing to leaching for the 0-10 cm depth; *Total soilwater* (mm) is soil water between air dry water content and saturated water content (mm) of the soil profile or the layer contributing; *LE* is the leaching efficiency parameter portioning soil water nitrate concentration into various pathways and *D* is the daily or monthly drainage (mm). The combined model was applied to a typical dairy farm in West Gippsland, Australia for the period of 1990 to 2005. The dairy farm attributes included: stocking rate of 2.5 cows ha^{-1}; fertiliser application of 200 kg-N ha^{-1} yr^{-1} as urea in 6 splits; and 4.7 t-DM ha^{-1} yr^{-1} of concentrate and forage fed (equivalent to an input of 110 kg-N ha^{-1} yr^{-1}). The farm was situated on a Dermosl_Chromosol heavy soil and received 1051 mm yr^{-1} rainfall over the 16 years. Model parameter sensitivity was assessed stochastically by a global sensitivity analysis procedure.

The annual total N export of 0 - 21 kg-N ha^{-1} estimated in runoff using the combined model is comparable to 0.06 – 12 kg-N ha^{-1} reported for the same soil with similar farm management characteristics in the Gippsland region (Barlow et al., 2007; *Nutrient Cycling in Agroecosystems*, 77, 69-82). Dissolved N was the major form of N loss in runoff, representing up to 84% of the total N. Predictions of nitrogen leaching from the dairy system of 71 kg-N ha^{-1} yr^{-1} was comparable to 79 kg-N ha^{-1} yr^{-1} reported by Ledgard et al. (1999; *Journal of Agricultural Science*, 132, 215–225) for dairy with similar environmental conditions and fertilizer application rate, but with a stocking rate of 3.3 cows ha^{-1}. Of the 19 parameters considered, those found to most impact N leaching estimates were root depth, green cover, maximum drainage limit of the sub-soil and field capacity of sub-soil. DN losses were most sensitive to green cover, DN_{soil} and k. In conclusion, the combined model was able to capture the important climate-soil-animal-pasture management interactions to predict N losses at annual scale. Global sensitivity analysis enabled an efficient means to investigating prediction sensitivities over the full range of parameter variations and combinations.

Key words: *Nitrogen leaching, N runoff losses, global sensitivity, dairy systems*

Estimating the impact of grazing industry on catchment nitrogen loads of the Moe River catchment

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Abstract: Intensification of grazing industry management is a cause of concern as a potential source of nitrogen (N) pollution at the catchment scale. To explore the impact of grazing industry and its management on N loads, a point-to-catchment approach was developed in this study. Point-scale N losses in leaching and runoff were estimated with two models, DairyMod and HowLeaky, for unique combinations of management, soil type, and climate (i.e. Hydrological Response Units, HRU). HRU N losses were divided in dissolved N (nitrate) in runoff, particulate N in runoff, and dissolved N in leached below the root-zone. The Catchment Scale Management of Distributed Sources Model (CatchMODS) was used to assess annual average nutrient budgets at the catchment scale. The spatial units were subcatchments, which comprised a river reach and the area (of about 20-60 km^2) delivering water, sediment and nutrients to it. River reaches were connected to upstream and downstream reaches in a node-link system. Subcatchment annual average N loads in runoff were assigned proportionally to HRU area in each subcatchment, and adjusted for topography. N loads from leaching were estimated from subcatchment average monthly N concentration in the soil water below the root zone and the monthly volume of subsurface water reaching the stream; monthly loads were summed over the simulation period and divided by the number of years to get the annual average leached N load. Total N loads generated by streambank and gully erosion were estimated from erosion rates and N content of gully and streambank eroding walls. In-stream attenuation of total N was modeled as a first order decay exponential function, assuming an inverse relationship between in-stream removal and stream size. The model was applied to the Moe River catchment in West Gippsland to assess the impact of grazing management intensification on TN loads at the catchment outlet. The uncertainty in TN load predictions due to catchment model parameters was assessed with a Bayesian inference method, following the Flexible Model Environment (FME) procedure implemented in R. Sensitivity and identifiability analyses were conducted to screen sensitive parameters and identify parameter sets that could be concurrently assessed. A Markov-Chain Monte-Carlo (MCMC) analysis was conducted to obtain parameter sets conditioned on mean annual flow and average annual sediment and nutrient loads observed at the outlet. These conditioned model parameter sets were then used in Monte Carlo Simulations (MCS) to propagate model uncertainty in land use scenario analysis. Of the 15 initial catchment model parameters, four upscaling parameters that regulated transfer of water, sediment and nutrients from HRUs to the subcatchment could be successfully conditioned using water quantity and quality data observed at the outlet: the fraction of water surplus to stream discharge *F*; the hillslope sediment delivery ratio *SDR*, and the in-stream nutrient attenuation parameters. Of 5000 MCMC simulations, 3431 were accepted. The best posterior parameter set resulted in a TN load of about 440 t TN y^{-1} at the outlet, which was very close to TN load estimated from monitoring station data (430 t TN y^{-1}); TN sources largely coincided with areas dominated by dairy land use. The MCS runs showed that intensity of grazing management had a significant impact on TN loads: intensification of the dairy industry based on increasing use of N fertiliser could triple current TN loads, up to about 1350 t TN y^{-1}. Conversely, extensification (little or no use of N fertilizer) could reduce TN loads to about 30% (i.e. 110-140 t TN y^{-1}). Other sources of uncertainty, most notably uncertainties in point-scale model inputs and uncertainties in model structure, could also impact model predictions, but they could not be assessed because of insufficient data. However, because of their upscaling function, the four parameters that were assessed are believed to characterize most of model uncertainty, and may help buffer propagation of uncertainty from point-scale inputs. Notwithstanding the uncertainty in model results, grazing management intensity was identified as having a major impact on TN loads reaching the Moe River catchment outlet.

Keywords: *Upscaling modeling, uncertainty analysis, Flexible Modelling Environment*

Nitrogen cycling under urine patches: Model comparison and sensitivity analysis

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Abstract: Agricultural greenhouse gas (GHG) emissions, including nitrous oxide (N_2O), are a major contributor to New Zealand's GHG emissions, and animal excreta deposited onto pastures are a main source of these emissions. Reducing these N_2O emissions requires a better understanding of the factors driving emissions and evaluation of mitigation strategies. Computer simulation models can provide an effective tool for these tasks. We compared two process-based models, APSIM and NZ-DNDC, on results of three experiments on N_2O emissions following urine application to the Horotiu soil in the Waikato region of New Zealand in various seasons and years. Soil ammonium and nitrate concentrations were also determined in the experiments. With default parameter settings, both models predicted the daily pattern of N_2O emissions poorly (Figure 1) with negative model efficiencies. The sensitivity of various model parameters was examined: For APSIM these included the nitrification rate, the optimum soil temperature on nitrification, the fraction of nitrified N emitted as N_2O, the denitrification rate, and the rainfall intensity. For DNDC they were microbial activity, nitrification rate, denitrification rate, plant growth, ammonia volatilisation, rainfall intensity, and fraction of N_2O produced during nitrification were varied. Changing some of the default model parameters improved the model agreement in some cases; e.g. for APSIM when the fraction of nitrified nitrogen emitted as N_2O was increased or the optimum temperature for nitrification was decreased, and for DNDC when microbial activity was decreased or volatilization increased. However, none of the parameters investigated could improve predicted emissions so that they agreed reasonably with all three datasets. A sensitivity analysis which includes more parameters and model functions, as well as changing various parameters simultaneously is needed.

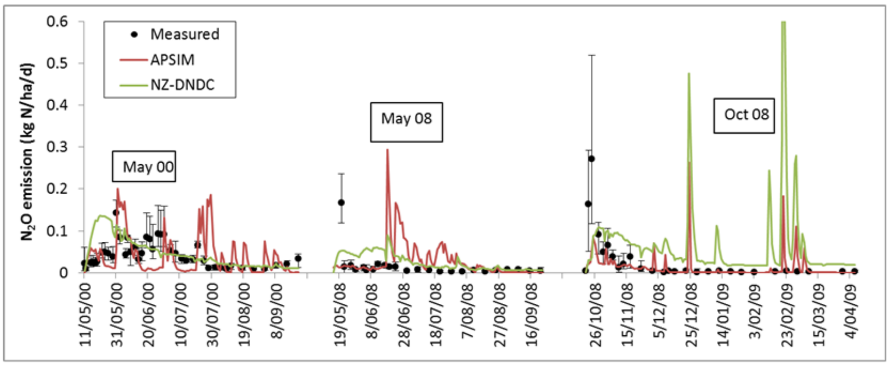

Figure 1. Measured and simulated, based on default parameters, N_2O emissions following urine applications of 500 to 600 kg N/ha at three different times to the Horotiu soil.

Keywords: *APSIM, DNDC, nitrous oxide emissions, soil nitrate and ammonium*

EXTENDED ABSTRACT ONLY

The uncertainty in predicting average quantities with simulation models

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Abstract: Often, model predictions are for individual elements in time or space while real interest is in some quantity averaged over time or space. For example, in evaluating the impact of climate change, we are mainly interested in yield averaged over years (e.g., a 30 year period), but the model predictions are output year by year. In these cases, evaluation is usually based on the individual model predictions. However, model quality might be quite different for the averaged quantities. Specifically, we would like to know if it is systematically true that models predict averages better than individual quantities. If so, what determines the improvement when predicting averages? Can we use commonly available data to estimate the improvement in predicting averages?

We use mean squared error (MSE) as our measure of the agreement between simulated and observed values. To make the discussion more concrete, suppose that we have measurements for the same field in several years, and we are interested in simulating yield averaged over years. (The approach applies equally to any other type of averaging). The two quantities we want to compare are average MSE (average over the individual years) and MSE of the average. These are defined as $aveMSE_i = (1/n)\sum_{j=1}^{n}(y_{i,j} - \hat{y}_{i,j})^2$ and $MSEave_i = ((1/n)\sum_{j=1}^{n} y_{i,j} - (1/n)\sum_{j=1}^{n}\hat{y}_{i,j})^2$ respectively, where the index i identifies the field and j the year. Chebyshev's sum inequality says that $aveMSE_i \geq MSEave_i$, with equality only if $y_{i,j} - \hat{y}_{i,j}$ is identical for all j. That is, it is systematically true that models predict averages better than individual quantities. The difference, $aveMSE_i - MSEave_i$, depends on the extent of the differences between $y_{i,j} - \hat{y}_{i,j}$ for different years.

In general, errors in different years will have some totally random component, due in particular to measurement error. There will also in general be some systematic component, due to systematic model error. To estimate these separate contributions to error we propose to fit a linear random effects model to model errors. The model is $y_{i,j} - \hat{y}_{i,j} = \mu + \alpha_i + \varepsilon_{i,j}$ where μ is the mean of model error (overall model bias), α_i is a random field effect (random between fields but fixed for a given field) and $\varepsilon_{i,j}$ is the residual. All the random effects are assumed to be mutually independent, with distributions $\alpha_i \sim N(0,\sigma_\alpha^2)$ and $\varepsilon_{i,j} \sim N(0,\sigma_\varepsilon^2)$. It is then easily shown that $E(aveMSE) = \mu^2 + \sigma_\alpha^2 + \sigma_\varepsilon^2$ and $E(MSEave) = \mu^2 + \sigma_\alpha^2 + \frac{\sigma_\varepsilon^2}{n}$ where n is the number of years in the average. It is the residual error, which is independent between years, which decreases when calculating error of the average. The quantities μ, σ_α^2 and σ_ε^2 can be estimated using any standard statistical package.

We applied this approach to two examples. The first involves a model for nitrous oxide emissions. The measurements are daily emission values, but real interest is in emissions over a growing season or longer. The second involves comparing different irrigation strategies for maize. The measurements are for individual years, but real interest is in performance averaged over years. We found that $aveMSE_i - MSEave_i$ is expected to be appreciable in both cases.

These results suggest that models may be much better predictors than indicated by standard evaluation techniques, if they are applied to estimating quantities averaged over time or space

Keywords: *model evaluation, mean squared error, , nitrous oxide emissions, irrigation*

EXTENDED ABSTRACT ONLY

Uncertainties in soil carbon modelling caused by model initialization and parameterization

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Abstract: Process-based biogeochemical models have been increasingly used to evaluate management options that have the potential to increase soil organic carbon (SOC) content. Due to the conceptual nature of the soil organic matter (SOM) pools in most models, these pools cannot be directly measured and can only be empirically initialized based on measured total SOC contents in the soil profile, and to some extent the experience of the modeller. Further, due to difference in pool structure definitions between models, contrasting approaches have been adopted to initialize the SOM pools – some based on measured SOC fractions, while others relied on the partition of SOC at an equilibrium state. Model initialization and parameterization are often conducted to ensure that the models can reproduce the measured SOC changes in the past. However, how the different approaches to initialization and parameterization affect the predictions of future SOC change has been rarely investigated, and this is the focus of this study.

The Agricultural Production Systems Simulator (APSIM v7.4) was used to simulate the dynamics of soil carbon and nitrogen at three sites (Brigalow, Tarlee and Wagga Wagga) in Australia, covering different climates, soils and cropping systems. At start of simulation, the conceptual SOM pools in APSIM (FOM – fresh organic matter, BIOM – microbial biomass, HUM - humus, IOM – inert C) were initialized using two approaches: MOD1 - with measured total SOC and partitions to each pool based on an empirical approach, and MOD2 - with measured SOC fractions (POC – particulate organic C, HOC – humic organic C, ROC-resistant organic C). In approach (1) the default decomposition rates of the pools were used. In (2) the decomposition rate for each pool was derived by parameter optimisation at the Brigalow site, and then used at the two other sites. The simulated crop biomass, grain yield, soil carbon and nitrogen dynamics were then compared with the measured values. In addition, the model was run with long-term (100 years) weather data at each site to simulate the equilibrium SOC at different levels of nitrogen fertilizer applications

Preliminary simulation results indicated that with the empirical initialization of the conceptual pools, APSIM was able to simulate the dynamics of total SOC in the surface 0.3 m of soil at all three sites from 1980s to early 2000s, where SOC declined with time due to cropping. APSIM also reasonably simulated the crop biomass and total soil N in the surface 0.3 m of soil at the Brigalow site. When the SOM pools in APSIM were re-initialized with the measured SOC fractions, the derived potential decomposition rates for POC and HOC were significantly different from the default decomposition rates of the FOM pools and HUM. With the newly derived decomposition rates, the model was able to capture the measured changes of each SOC fraction (POC, HOC and ROC) and the total SOC with time. However, the re-parameterized model was not able to simulate the dynamics of nitrogen in the top 0.3 m of soil.

Results from the long-term simulations revealed that the re-parameterized model simulated a significantly higher equilibrium SOC (0-0.3 m) than the original model, particularly at Tarlee and Wagga Wagga and at high N application rates. This was mainly due to the reduced decomposition rate of HOC pool, leading to less SOC decomposition, even the simulated residue return was similar.

The result from this study pointed out potential uncertainty in the modelling of soil organic carbon change as caused by different model initialization and parameterization. This uncertainty means that reasonable simulations of the past experimental data may not guarantee confident simulations into the future, even the future conditions can be predicted with confidence.

Keywords: *Soil carbon sequestration, soil nitrogen dynamics, Soil organic matter pools, APSIM*

Modelling the response of N_2O emission factor to nitrogen application rates and inter-annual climate variability

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Abstract: Nitrous oxide is one of the primary greenhouse gases contributing to global warming, and its concentration in the atmosphere has increased significantly since 1970. Agricultural soils are regarded as the most important source for emissions nitrous oxide. The Intergovernmental Panel on Climate Change (IPCC) put forward 1.0% as the default country-specific value for emission factor (EF) for estimating country-specific direct nitrous oxide emissions from nitrogen input agriculture. However, the emission factor from soils is based on limited data. Large uncertainty had been found in the EF values as no allowance has been made for the effects of land cover, soil type, climatic conditions or management practices on the values. In this paper we use Agricultural Production Systems simulator (APSIM) to explore the response of EF to N fertilizer applications and climate variations. The model is used to predict emission factor following various N-fertilizer rates over a 120 years (1890-2010) in a semi-arid rain-fed wheat cropping system in New South Wales, Australia. Emission factors following N application to rain-fed wheat ranged from 0.13-0.23%, which was significantly lower than the default emissions factor recommended by IPCC (EF=1.00%). Our long-term simulation results clearly showed that EF increased linearly with N inputs, and there was a highly variable inter-annual climate. In the rain-fed wheat cropping system, highest EF occurred in years with medium rainfall years, which indicated that the proportion of N-fertilizer inputs loss as N_2O emissions was not only highly impacts by annual rainfall amount but also rainfall pattern.

Keywords: *Emission factor, Climate variability, N-fertilizer rate*

River Red Gum Response to Extended Drought, High Flow and Flooding along the River Murray, South Australia

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Abstract: The Murray-Darling Basin has experienced significant ecosystem degradation driven by land-use change, irrigation and urban and industrial abstraction. The long-term 'Millennium Drought' between 1997 and 2009 and subsequent wet years provided an opportunity to examine ecological responses of floodplain assets to extended drought followed by high flows and flooding. *Eucalyptus camaldulensis* (D.Dehn; River Red Gum) is one of three key tree species which dominate the floodplain, and is highly dependent on flood frequency, requiring inundation every three years to five years.

This study investigates the relationship between River Red Gum condition, flooding and in-channel flows between 2007 and 2011 using satellite remote sensing imagery. Spatial techniques utilising remote sensing data offer the ability to investigate floodplain ecological responses over large areas by linking ecological responses to hydrological data and inundation extents. The study aims to improve our understanding of hydrological connectivity between river and riparian zones and the benefits of increased water availability under future environmental flow management.

A GIS-based approach was undertaken to examine the response of River Red Gums using Landsat NDVI to monitor changes in vegetation vigour in various floodplain areas pre and post flooding. Analysis was carried out across a range of both river-connected *E. camaldulensis* polygons and those disconnected from the River Murray during the drought. The influence of lateral bank recharge on floodplain River Red Gum communities was investigated using distance buffers extending perpendicular from adjacent surface water bodies.

Results indicate that a lateral recharge zone of influence up to 90m from the River Murray channel and feeder creeks maintains River Red Gums in better condition compared to areas beyond 120m from a delivery channel, and stress the importance of wetland connectivity. Temporal analysis linking River Murray flow, inundation duration and River Red Gum condition using the River Murray Floodplain Inundation Model (RiM-FIM) and NDVI, indicate that River Red Gum response to flooding is greatest when inundated between 7 and 60 days. Continual high flows of 71-74 GL day^{-1} are required to reach this target. While the trees may tolerate longer periods of inundation if they are in good condition, drought-stressed trees are unlikely to respond well to inundation durations beyond 60 days. Results also indicate that the flow duration and magnitude of the 2010/2011 flood was lower than required to meet the environmental water requirements of both River Red Gum forest and woodlands for the Chowilla floodplain.

Lateral bank flow, flooding and wetland connectivity are therefore essential in maintaining and improving River Red Gum health within the South Australian section of the Murray-Darling Basin. The 2010 and 2011 floods were insufficient to meet the Basin Plan targets of 30 days inundation for *E. camaldulensis* forest and woodland areas to maintain 80% of trees in good health. Additional environmental flows 'piggy-backed' on the flood peak are likely to be necessary to increase inundation extent and duration within the Chowilla floodplain in South Australia.

Keywords: *River Murray, floodplains, flood modelling, drought*

GIS-based spatial zoning for flood inundation modelling in the Murray–Darling Basin

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Abstract: Flood inundation modelling for ecological purpose is important for the Murray-Darling Basin (MDB). It is necessary to divide the basin into hydrologically similar but ecologically independent zones due to its complex topological and hydrological conditions. Pioneer studies in zone delineation at large basin scale have been proven to be successful. However, an outstanding issue identified in these studies is that the topography and hydrological connectivity have not been given enough consideration, which results in the lack of explicit spatial connectivity between zones.

In this study, the Australian Hydrological Geospatial Fabric (Geofabric) published by the Bureau of Meteorology of Australia was employed to classify the MDB into eco-hydrological zones. The Geofabric is based on a variety of topological data and has a consistent representation of hydrological features and their connectivity, which are crucial for spatial zoning. Several zoning criteria were established taking into consideration the gauge location, flow data quality and availability, and landscape integrity. Based on these criteria, a number of neighbouring catchments in the Geofabric were combined to generate an eco-hydrological zone. A representative gauge was selected for each zone to best reflect the flow that goes through it. All zones are spatially and hydrologically connected via a stream network. Improved relationships between flow and inundation, and spatial pattern of inundation extent have been achieved compared to the existing zones. It is hoped that the derived zones will be able to help develop floodplain inundation models that can be easily integrated into the Geofabric-based geospatial framework.

Keywords: *hydrological spatial zoning, flood inundation modelling, gauge flow, Geofabric*

Ribbon Plots – A Spatial Flow Analysis Tool for Stable Multiple-Channel Drainage Networks

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Abstract: Quantitative, landscape-scale hydrological and geomorphic analysis of remote, multiple-channel river reaches is hampered by a lack of representational tools, and measurement difficulty during significant flow events. A "black box" input/output modelling approach obscures spatial distribution of flow. At the other extreme, small-scale localised studies may be insufficient to identify landscape-scale emergent patterns. Fieldwork is infrequent, and often impossible during flows, and existing remote sensing tools are difficult to interpret and adjust using a monthly (or finer) resolution over a decadal timeframe.

The "Ribbon Plot" has been developed to concisely represent the spatial distribution of characteristics such as vegetation, moisture, and sediment size along pathways within a complex anastomosing system, as derived from remote-sensed data. This paper presents the concept using a limited dataset.

A Ribbon Plot is a linearised simplification of a complicated floodplain channel network. A set of plots is generated from spectral data, and arranged to reflect the study area configuration. The ribbons are read in the normal direction of flow – down the page for downstream – and in time sequence - left to right. Each image results in one set of ribbon plot columns with the same horizontal time coordinate. Colours are used to represent spectral index numerical values at each observation time.

The Ribbon Plot format can be tailored and updated for a desired study objective, using the latest available data for areal extent, spatial resolution, timespan, temporal resolution, and input source, as well as uncertainty estimation. A large amount of heterogeneous information can be compressed into a compact format, to reveal spatial or temporal patterns for interpretation by environmental scientists.

A small Ribbon Plot example has been developed using a 20 km x 20 km portion of the large and complicated Cooper Creek/Wilson River floodplain (Lake Eyre Basin, Australia), with spectral data extracted from standardised Landsat images for the period December 2003 to September 2004. The example demonstrates the distribution of NDVI responses (as a proxy for the presence of water) over time during a significant flow event, revealing patterns of differing flow durations and areas of increased persistence.

Keywords: *Multiple-channel rivers, drainage networks, flow spatial distribution, remote sensing*

Development and evaluation of a spatially explicit habitat suitability model for River Red Gum on the Murray River using an inundation model

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Abstract: The River Red Gum (*Eucalyptus camaldulensis*) is a widely distributed tree species occurring in frequently flooded riparian habitats and wetlands throughout the Murray-Darling Basin. River Red Gums providing important habitat and contribute to maintaining ecosystem health. River regulation in the Murray-Darling Basin has greatly altered the natural flow regime in many river catchments leading to the degradation of riparian and wetland ecosystems, including the condition of many River Red Gum communities.

The Murray-Darling Basin Plan aims to supply environmental water to sustain areas of ecologically significant floodplain communities. This is to be achieved through regional and basin-scale environmental watering plans aimed at returning flows to the river system to maintain ecological function. Environmental watering plans often specify flow peaks that are needed to maintain environmental assets, however the spatial context to the inundation of surrounding wetlands and floodplains is often limited. There are few spatial floodplain models for predicting the ecological outcomes of different river flows in the Murray-Darling Basin.

Habitat suitability models are typically static representations of a biophysical environment that profile a species environmental requirements. Such models are often used to predict the suitability of habitat to facilitate a species recruitment or persistence under specific conditions. Habitat suitability models are often used by resource managers to predict the outcomes of different management strategies, including determining the flow requirements and the potential outcomes of different environmental flow releases. This paper introduces a spatial habitat suitability model for use in assessing the habitat suitability for the iconic River Red Gum. The model considers flow as the main driver, with flows being represented as peaks and durations for the maintenance of River Red Gums at two reaches along the Murray River. The hydrological preferences of the River Red Gum forest and woodland varieties were combined to get a single inundation return interval range, with the effect of inundation duration also considered.

The RiM-FIM inundation model was used to represent the flood extent of flows at each site, with spatial envelopes of habitat suitability determined based on inundation return intervals. The affect of land use was considered by removing towns and agricultural areas from the study area. The predicted extents were compared to observed data and the model outcomes were evaluated by calculating the omission and commission errors. The model outcomes suggested predictions of extent were improved when duration was excluded. Correcting for land use further increased the accuracy of the model.

As part of this paper, we discuss improvements to our approach, including improvements in model conceptualization. The model currently only considers the maintenance requirements of mature River Red Gums. However, different parts of the lifecycle have different watering requirements. Expanding the model to include different lifecycles would lead to a more holistic approach to modelling habitat suitability for River Red Gums.

Another potential improvement is in representation of floodplain inundation. The model currently uses a static representation of floodplain inundation, with the same flow at the gauge assumed to have the same inundation pattern. However, flooding over floodplains is highly dynamic, with changes to land use and development of infrastructure influencing the patterns and extents of inundation. Using a hydrodynamic modelling approach may provide a more accurate representation of the floodplain inundation process.

Keywords: *Habitat suitability modelling, River Red Gum, Murray River*

Using MODIS for mapping flood events for use in hydrological and hydrodynamic models: Experiences so far

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Abstract: Daily, or more frequent, maps of surface water have important applications in environmental and water resource management. In particular, surface water maps derived from remote sensing imagery play a useful role in the derivation of spatial inundation patterns over time and in calibrating and validating hydrological and hydrodynamic models. While MODIS data provide the most realistic means to achieve this, they are often limited by cloud cover during flooding events, and their spatial resolutions (250 – 1000 m pixel) are not always suited to small river catchments. This paper tests the suitability of MODIS for providing daily surface water maps, both spatially and temporally, across a range of Australian catchments. This study shows that MODIS is suitable for capturing both medium and large flood events, but lacks the detail around the edge of a flood or along narrow water features where it tends to underestimate water extent. Compared to a Landsat water map, the MODIS water maps have shown a strong-to-moderate statistical agreement. Soils are sometimes mapped as wet when they are not, possibly due to confusion with moisture in the soil and/or soil colour. Flooding under dense vegetation is often invisible to MODIS or any other optical remote sensor. Care must also be taken when using MODIS data along the edge of the image swath where the water extent can be underestimated. The view angle, or range distance from sensor to pixel, influences the amount of water that can be mapped, as is demonstrated with a permanent water body. On a temporal scale, cloud cover often inhibits the use of MODIS imagery at the start and lead-up to the peak of a flood event, but there are usually more cloud-free data to monitor the flood's recession. MODIS surface water maps are sensitive to the dynamics of water movement when compared to flow gauge data. Given their temporal and spatial characteristics, the MODIS sensors can provide useful information for hydrodynamic modelling, and do appear to be the best available product for mapping inundation extent and its change dynamics at large regional/basin scales.

Keywords: *Optical remote sensing, surface water mapping, flood inundation*

Assessing stream restoration works in the southern Macquarie Marshes using hydrodynamic modeling

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Abstract: The Macquarie Marshes are an extensive wetland system located in central New South Wales within the lower Macquarie Catchment, representing one of the largest semi-permanent wetlands in south-eastern Australia. The Marshes are one of most biologically diverse wetland systems in the Murray Darling Basin, and support some of the largest waterbird breeding events in Australia. A number of studies have demonstrated the critical role of inundation in maintaining the ecological values of the Marshes. The inundation extent, duration and depth of the core wetlands in the Marshes are variable over long and short time-scales, related to geomorphology and flow variability in the Macquarie River.

Processes of sedimentation and erosion underlie channel changes in the Marshes and have created a range of landforms with distinct characteristics and spatial distribution. As channels change and move on the floodplain, flooding and sedimentation patterns change and the wetlands respond by relocating, expanding and contracting. The streams and wetlands of the southern part of the Macquarie Marshes have been associated with notable hydrological and geomorphic changes over recent history including channel erosion, changing flow paths and reductions in wetland inundation. Some wetlands have been partly or wholly abandoned by the modern streams (e.g. Macquarie Terminus Marsh and Willie Marsh), while ecologically important wetlands have also developed and changed over time (e.g. Willancorah Swamp). In addition to natural fluvial landforms, there are many anthropogenic features (e.g. roads, levee banks, regulators and channels) that modify the natural landscape and influence flow in the system.

While channel change over time is a significant factor for wetland conservation, the impacts of channel change and potential intervention scenarios have never been assessed at the wetland system or sub-system scale in the South Marshes. In this study, we built a 1D/2D coupled hydrodynamic model (MIKE FLOOD) at fine spatial resolution (30 m) for the South Marshes. The MIKE FLOOD gives us the ability to evaluate the impacts of channel change on flow distribution both within channels and on the floodplain. We constructed and simulated three scenarios representing the baseline (i.e. no change to the current channel depth as in 2008), worsening (i.e. erosion keeps on going resulting deepened and built-up channels), and improved (through channel stabilizing etc.). The flow distribution and inundation extent under the three scenarios were compared for low, medium and high flows. The results showed that there were substantial differences in flooding patterns in terms of river flow distribution, flow breaking (into floodplain) locations, and inundation extents even for low flow conditions. However, the biggest changes were for medium flow. The study demonstrated that hydrodynamic models could be a useful tool in floodplain restoration through comparing the outcomes of alternative remediating works and predicting the outcomes of proposed works on wetland system hydrology and inundation patterns.

Keywords: *Geomorphology, MIKE FLOOD, Inundation, Channel erosion, South Macquarie Marshes*

An integrated source-fate-effects model for sedimentary metals in Sydney estuary and catchment (Australia)

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Abstract: Sediments in Sydney estuary (Australia) and soils of the catchment are highly enriched in copper (Cu), lead (Pb) and zinc (Zn) and these metals are accumulating in tissue of estuarine fauna. To reduce contamination levels, especially in the tissue of bivalve filter-feeders, it is necessary to understand the processes linking source, fate and effects of metals in these environments. It was the aim of the current work to identify key mechanisms controlling bioaccumulation in shellfish inhabiting this estuary by combining the results of existing individual models and monitoring data (oyster soft-tissue concentrations) describing various parts of this system into a single source-fate-effects model. Of the existing models, an atmospheric model (TAPM) showed that vehicle emissions were the major contributor of metals to catchment soils while stormwater modelling indicated that the average annual discharge from Sydney estuary catchment ranged 215,300 - 372,000 ML with associated loadings of 60,400, 30.5, 49.0 and 89.2 tonnes for total suspended solids (TSS), Cu, Pb and Zn, respectively. A verified hydrodynamic model investigated estuarine response to catchment rainfall and showed that fresh-water plumes generated during high-rainfall events broke down within the estuary and that minimal (<1%) associated contaminants exited the estuary to the ocean, whereas TSS and pollutants delivered during low-rainfall were deposited close to discharge points and were trapped within the estuary. Oyster (*Saccostrea glomerata)* tissue was highly enriched in these metals, however there was no significant relationship with bottom sediment metal concentrations.

The integrated model used here comprised a process-based framework describing the water and sediment balance coupled to a chemical (Cu) speciation model and an oyster bioaccumulation model. This integrated model is not spatially explicit on the horizontal plan but consists of two vertical components (aqueous layer and sediment). Early results of the source-fate-effects modelling indicate that the increase in dissolved and particulate organic ligands associated with a stormwater event entering the system appears unable to compensate for the concomitant increase in aqueous Cu and that the excess may be associated with dissolved inorganic ligands after the organic complexation sites have been exhausted. Modelling provides evidence that mechanisms driving pollution in the estuary are sensitive to catchment loading rates, which may result in highly variable soft-tissue Cu concentration in oysters.

Keywords: *Metals, atmospheric deposition, fluvial loading, Sydney estuary, hydrodynamic, vehicles*

EXTENDED ABSTRACT ONLY

Generalized additive modelling helps untangle East Australian coastal processes

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Abstract: The high level of investment in coastal infrastructure along the Gold Coast (Queensland) and Northern New South Wales makes this area possibly the most financially at risk region to the impacts of sediment supply, coastal erosion and sea-level rise in Australia. The area is dominated by southeast winds and waves forcing a net northerly littoral drift in the surf zone with sediment sourcing eroding beaches and sediment sinks blocking estuary mouths. During severe storms and strong East Australian Current eddy events, sediments can be transported further offshore and deposited on the inner shelf. Furthermore, uplift and upwelling could be an influencing factor for cross shelf transport but often appear to have no association with local wind conditions.

Recent sediment transport field studies have concentrated within the surf zone leaving the inner continental shelf area from the outer surf zone to the 25-30m depth edge of the photic seabed less-well understood. To investigate this inner shelf region, Griffith University has deployed a number of focused monitoring campaigns with a moveable offshore monitoring platform moored at depths ranging between 20 and 30m. The developing offshore monitoring stations comprise an evolving suite of oceanographic instruments measuring a multitude of environmental parameters and have contributed to a comprehensive and long-term (effectively continuous) time series dataset.

Since the start of the project in 2005 with the Tugun de-salination background study, the large volume of data that has been collected has been used by various researchers to investigate a number of different coastal phenomena in the region. In particular, the large amount of data provides an opportunity to apply sophisticated statistical approaches for exploratory assessments. For example, non-parametric statistical methods such as locally weighted scatter plot smoothing and Seasonal Mann-Kendall test are often used to provide insights into potentially nonlinear and multivariate relationships between response and predictor variables of interest. One such approach, generalised additive modelling (GAM), appears to be, in particular, an effective methodology for disentangling causal relationships from the data emerging from the inner-shelf monitoring. To date, GAMs have been applied sparingly to the coastal zone but their track-record in air quality studies and their ability to account for nonlinear confounding effects of seasonality, trends and weather variables makes them appear very suitable for the task of evaluating and exploring large water quality datasets.

To highlight the relationship between data collection and assessment, this paper also describes the development of an 'instrument' through a case study where repeatable and accurate measures of turbidity were sought. The context for this data collection was the evaluation of a candidate location to be used as a tourist dive site and therefore turbidity is an important (and measureable) indicator of water visibility. There is also interest in the physical processes occurring at, and within close proximity to, the candidate site because these potentially influence turbidity and also the ability to access and utilise the candidate site for diving. To further emphasise the utility of the data collection, we present and discuss the findings of a GAM-based assessment of the turbidity data, in particular the functional relationships that emerged between turbidity and the predictor variables. The outcome of this study can be used to guide local government policy decisions and provide a better understanding of the inter-relationships between various coastal and oceanic processes.

Keywords: *Ocean observatory, sediment transport, GAM analysis.*

What is the Role of Sediment Resuspension in the Bioaccumulation of Heavy Metals in Oysters?

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Abstract: The Sydney estuary (Port Jackson) is a highly modified waterway in which surficial sediments are extensively contaminated by a suite of chemicals including trace metals. These surficial sediments undergo resuspension into the water column on a daily basis due to both natural and anthropogenic processes which includes tides, currents, bioturbation, shipping, and dredging. As a result, sediment resuspension significantly increases the risk of trace metal contaminant exposure to marine biota. The status of trace metal contamination in surficial sediments, suspended particulate matter, and aquatic organisms has been studied in detail, and in all three media high concentrations have been detected, particularly for Cu, Pb, and Zn. However, a significant relationship linking these processes together has yet to be made and the effect that sediment-bound trace metals inflict on local fauna has not been documented previously.

The current study aims to identify the processes controlling bioaccumulation of trace metal contaminants in Sydney estuary using laboratory-based mesocosm experiments. The native Sydney rock oyster (*Saccostrea glomerata*) was used as a bioindicator species and was exposed to contaminated suspended sediment at a range of controlled concentrations and loads to mimic previously observed field conditions. The oysters were analysed for total bioaccumulated tissue metal concentrations, as well as changes in protein expression to identify probable early-onset bioindicators.

The results from the laboratory experiments will be used to parameterise a biogeochemical model to help explain the different mechanisms of trace metal bioaccumulation in Sydney estuary.

Keywords: *Heavy metals, sediment resuspension, oysters, bioaccumulation, proteomics*

Integrated Modelling Approach for Climate Change Adaptation: The Case of Surf Life Saving Australia

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Abstract: Surf Life Saving Australia (SLSA) is Australia's main water safety and rescue authority whose assets and operations include 310 local surf lifesaving clubs and about 150,000 trained volunteers. Rising sea level and increased extreme events frequency pose serious threats to SLSA's assets and facilities. Therefore, this research aims to explore adaptation pathways and strengthen the capacity of SLSA to tackle these threats.

However, adaptation to climate change is very complex and encompasses a range of constraints such as reliable data, information, time and uncertainty which make quantification quite difficult. To overcome these challenges, the research team has utilised an array of techniques into a cohesive approach including participatory workshops, MIC-MAC and System Dynamics (SD). Through stakeholder engagement (workshops) and structural analysis (MIC-MAC), key variables were identified and an influence dependence chart (causal relationship) was created. Then, using an SD approach, first a conceptual model was built to understand potential values of SLSAs services given sea level rise (SLR) controls, adaption options, and feedbacks within and between the climate change and SLSA operations. The SD model consists of three interactive sub-models: a) Climate change; b) SLSA Operation; and c) Community.

The climate change sub-model, under a range of SLR scenarios, simulates changes in storm events frequencies which are vital to SLSA's operation and assets. Therefore, adaptation investment on all forms of accessibility would reduce the impact of extreme storm events on a club's operation. A community sub-model is used to understand the impacts of changing climate, specifically resulting extreme events, on community located around clubs.

Keywords: *Surf life saving Australia, Integrated modelling, Climate change adaptation, System dynamics*

Systems Thinking and Modelling for Coastal Zone Management and Climate Change Adaptation

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Abstract Coastal areas are complex interconnected systems combining hydrodynamics processes, fragile ecosystems and human settlements. This combination can create complicated socio-environmental problems often resulting in uncertain management solutions, in particular in the light of climate change.

Systems thinking and modelling, considering natural, social and economic aspects, have become popular in the last decade as a way to provide a better understanding of coastal areas and climate change elements, connections and behaviour. Systems thinking is a methodological approach that aims at breaking down interlinked elements which can directly or indirectly influence one another. Systems-based methodologies place emphasis on understanding and describing the nature of these elements and relationships, resulting in a conceptual model of the system. Systems modelling is the process of turning conceptual models into computer models ready for simulations. This quantification provides a numerical tool that can be used to understand or predict how a system will respond to changes.

With the support from the Griffith Climate Change Response Program, the Systems Thinking and Modelling Group was recently formed to gather expertise in systems thinking and modelling within Griffith University, to provide a better understanding of socio-environmental systems in coastal areas under the impacts of climate change. A range of research activities has been carried out by the group members, developing or combining techniques which often rely on stakeholder contribution as a starting point for more sophisticated modelling, for instance:

- To identify adaptation options and adaptive capacity determinants for South East Queensland coastal settlements
- To identify and assess a range of climate change and coastal hazards options for Surf Life Saving in Australia assets and operations, including the analysis of the stakeholders networks
- In eliciting quantitative stakeholder driven scenarios as an output for use in interdisciplinary modelling for offshore aquaculture development in California
- In modelling adaptation to sea level rise combining spatial data with system dynamics simulations.
- In identifying coastal management indicators (Sano & Medina, 2012) and, in particular, in modelling stakeholder mental models of relationships between coastal issues in Egypt.

The outcomes of these experiences show that systems approaches are able to provide a better understanding of coastal systems in a changing climate by gathering different views and mental models from stakeholders and producing quantitative analysis and outputs. This information can be practically used to support decisions and indirectly employed to foster dialogue and create consensus within stakeholders groups.

Keywords: *Systems Thinking, Systems Modelling, Coastal Zone Management, Climate Change Adaptation*

Hydraulic modelling of predicted sea level rises in Kakadu Flood Plains

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(Work conducted in partnership with the Northern Territory Biodiversity Hub (NERP))

Abstract: Kakadu National Park is a UNESCO World Heritage site listed for its cultural and ecological significance. There is therefore a shared responsibility for ensuring the sustainability of the ecosystems and the preservation of the cultural heritage in Kakadu National Park. There are four tidal rivers within Kakadu National Park, the South Alligator, East Alligator, West Alligator and Wildmann River. Future sea level rises are expected to increase these rivers tidal zones. Moreover, the associated salinity effects threaten to detrimentally impact the vegetation and wildlife of the park. To inform the decision making and sustainable management of these rivers and coastal systems, we modelled the effects of predicted sea level rises for 2030, a 0.14 m rise, 2070, 0.70 m rise and 2100, a 1.10 m rise. The modelling approach used an inundation method based on the Shallow Water equations. Simulations were performed at a spatial resolution of 60 m^2 for each of the main river systems within Kakadu. We identified how the tidal extent was likely to change for each sea level rise scenario. From the predicted tidal extent we assessed potential impacts upon cultural areas significant to the traditional owners, wildlife habitat, vegetation and popular tourist areas. One area of particular interest was the mostly freshwater Boggy Plain, where we performed additional high resolution, 30 m^2 simulations to consider sea level rise impacts (Fig. 1). For all the simulations we used a Digital Terrain Model (DTM) constructed from Lidar point cloud data to resolve the coastal and river system terrains. Lidar data offers the high level of vertical accuracy, 0.10 m, necessary for analysing sea level rise effects, such as the sea level rise of 0.14 m predicted for the year 2030. To provide confidence to the simulated predictions, tidal and rainfall validation of past events was conducted, with good agreement to gauge measurements and flood inundation extent. The validation of a heavy rainfall event is important for understanding river connectivity, catchment flow and river discharge rates. Initial results for the sea level rise scenarios show significant increases in the tidal extents of the four rivers as compared with the current day. Simulations also suggest for a river elevation sustained above 3.3 m AHD, as predicted for the 2100 sea level rise, that saline intrusion will occur in Boggy Plain (Fig. 1). Future work for this project will include quantifying salinity saturation using diffusion between the freshwater from rainfall and saltwater from tidal or storm surge sources.

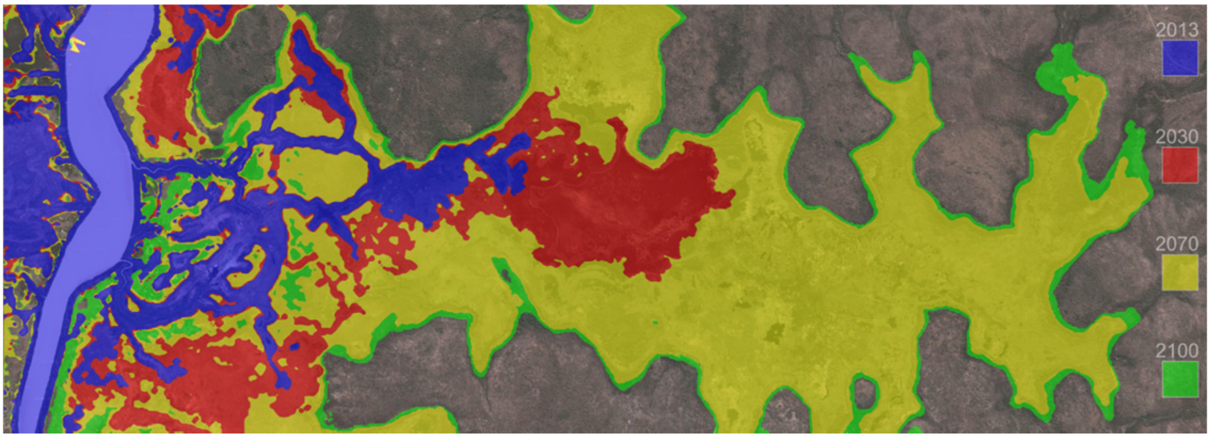

Figure 1: Simulations of sea level rise scenarios in Boggy Plain, a predominantly freshwater area connected to the South Alligator River. The colours indicate the tidal inundation extents and changes in saline intrusion.

Keywords: *Sea level rise, Kakadu National Park, Shallow Water, Hydraulic Modelling, Coastal Systems*

A Coastal Model Supporting Urban Catchment Management

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Abstract: This paper presents outcomes from the development of hydrodynamic model of Tallebudgera Creek, a small coastal creek in South-East Queensland, Australia. The entrance to Tallebudgera creek is situated on a coast which is subject to highly variable wave energy, including swell events derived from occasional tropical cyclones. A prevailing longshore sediment transport rate of approximately 500,000 $m^3 yr^{-1}$ is derived from an oblique wave approach due to the predominantly south-east wave direction. The entrance is subject to infilling by marine sands and is currently dredged annually to mitigate flooding impacts and to maintain water quality.

The model is calibrated with water level and discharge data and describes the flow behaviour for this well-defined hydrodynamic system with the inclusion of wave-current interaction at the entrance. The model was developed in order to simulate and to test the impact of a range of potential future management schemes for the creek, such as modifications to the entrance or changes to the present maintenance dredging regime.

The model was found to be sensitive to bed roughness at upstream locations more than at the downstream region. The presence of a weir-like structure upstream resulted in a modified tidal signal.

Keywords: *Hydrodynamic model, Tallebudgera Creek, tidal inlet, dredging, sediment transport*

Modelling of physicochemical processes in Lake Wivenhoe during a flood period

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Abstract: Wivenhoe Lake, which is situated 80 km west of Brisbane, is one of the largest dams in Australia and is especially designed to minimize flood risks for the city of Brisbane and its surrounding areas. After a decade-long drought, a heavy rainfall event occurred around the Wivenhoe catchment in early January 2011 and this quickly filled the dam. During the flood period a massive organic load, originating from vegetation surrounding the lake, entered and changed the dissolved organic matter (DOM) spatially and vertically across the lake in a very short period of time. DOM is of primary concern due to its role in the transfer of nutrients, heavy meals and other pollutants from surrounding terrestrial environments. DOM influences the physical and chemical environment in lakes through light attenuation and metal complexion. It is also important in trophic dynamics because it supports the growth of heterotrophic microorganisms. In addition, DOM can be responsible for water quality and disinfection by-products following chlorination in water treatment plants.

To understand DOM fluxes during a flood period, water samples were collected from Lake Wivenhoe at 5 locations and three depths in each location, namely at the surface (<0.5 m), middle (5 m) and bottom (>15 m) during the flood period using Niskin Water Sampler (4 L, Wildelife Supply Company, Yule, Florida, USA). The collected samples were filtered through 1.2 µm filters and analyzed for DOM using total carbon analyser, UV and fluorescent spectroscopy. The UV absorbance recorded at various wavelengths (200, 210, 220, 230, 240, 250, 260, 280, 300 nm) and excitation emission fluorescence recorded over 200 to 500 nm were used to generate DOM contour diagrams and patterns across the lake. Five major chemical groups: amino acids, aromatic amino acids, microbial by-products, fulvic acid and humic acid were studied in fluorescent spectra. Areas of peak volumes and ratios between volumes of the 5 regions were calculated. The major dominating chemicals were humic and fulvic acids.

The DOC analysis showed that levels were higher at the surface than at the middle and bottom depths. Also the middle and bottom depths did not show any trend. Decreases in the surface DOM from inlet to outlet were possibly due to settling of organic matter or decomposition by microbes or photochemical processes. The UV and fluorescence spectral data showed that organic species were distributed heterogeneously across the lake both spatially and vertically and were influenced by microbial activities. Figure 1 shows contour diagrams of UV spectral intensity of flood waters recorded at a wavelength of 254 nm in Wivenhoe Lake at the surface (left), middle (middle) and bottom (right) during the flood period in January 2011. Colour patterns in the contour diagram reflect the absorbance intensity at 254 nm.

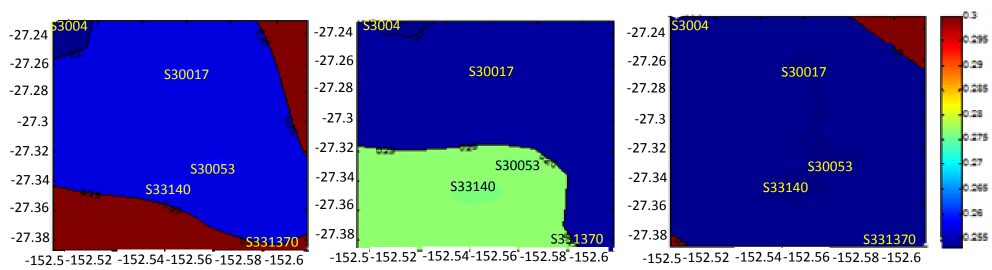

Figure 1: Contour diagram of UV spectral intensity of flood waters recorded at a wavelength of 254 nm at the surface (left), middle (middle) and bottom (right) of the lake.

Finally, the results demonstrated that optical spectra can be helpful for monitoring the physicochemical processes occurring across the lake and this information can be beneficial for water treatment and management.

***Keywords**:* *dissolved organic matter, lake, flood, UV spectroscopy, fluorescence spectroscopy*

Modelling Acidic Solute Fluxes to the Water Column in the Lower Lakes

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Abstract: During the recent drought in the Murray-Darling Basin in flow to the lower lakes was severely restricted, which led to a reduction in the lake levels to as low as -1.0 m AHD. This resulted in exposure of sediments with pyritic minerals and the subsequent oxidation of these to produce acidic sediments. Upon refilling of the lower lakes these sediments were inundated, providing a pathway for this acidity to be transport to the lake water. The rate of acidity (H^+, Fe^{2+}, Al^{3+}) transport to the lake water, the time course of acidity transport and the possible effects on the lake water alkalinity are not known. In order to provide some guidance on these issues, models to estimate the flux of this acidity to the lake water were developed.

These models were based on the analytical solutions for solute transport in porous media collated by van Genuchten and Alves (1982). The solution we used is a pulse input with a concentration of c_0, constant initial concentrations; c_1, in the sediment to a depth of z_1 and c_2 for $z_1 < z \leq \infty$, which results in the concentration being given by:

$$c(z,t) = c_2 + (c_1 - c_2)A(z,t) + B(c_0 - c_1),\ A(z,t) = \frac{1}{2}\mathrm{erfc}\left[\frac{R(z-z_1)}{2\sqrt{RDt}}\right] + \frac{1}{2}\exp\left(\frac{qz}{D}\right)\mathrm{erfc}\left[\frac{R(z+z_1)}{2\sqrt{RDt}}\right],\ B(z,t) = \frac{1}{2}\mathrm{erfc}\left[\frac{Rz-qt}{2\sqrt{RDt}}\right] + \frac{1}{2}\exp\left(\frac{qz}{D}\right)\mathrm{erfc}\left[\frac{Rz+qt}{2\sqrt{RDt}}\right] \quad (1)$$

where R is the retardation, z is depth (m), t is time (s), q is Darcy flux (m s^{-1}) and D is the dispersivity (m^2 s^{-1}). The solutes modelled were, H^+, Fe^{2+}, and Al^{3+} and total acidity, taken as H^+ equivalent of the metals.

Table 1. Modelled and measured flux rates (mol H^+ m^{-2} day^{-1}) from Hicks et al. (2009, Table 8). Negative values indicate flux from the sediment to the water column and positive values from the water column to the sediment. Advection results are for $q > 0$.

Location	Measured (mol H^+ m^{-2} day^{-1})		Modelled (mol H^+ m^{-2} day^{-1}) Diffusion only		Modelled (mol H^+ m^{-2} day^{-1}) Diffusion + Advection	
Boggy Creek	Day 1	Day 7 -102	Day 1	Day 7 -102	Day 1	Day 7 -102
Fresh water	-1.6×10^{-1}	-6.0×10^{-3}	-3.3×10^{-1},	-23×10^{-3}	-3.4×10^{-1}	-9×10^{-3}
Sea water	-5.3×10^{-1}	-22×10^{-3}	-9.1×10^{-1},	-73×10^{-3}	-8.4×10^{-1}	-20×10^{-3}
Point Sturt	Day 1	Day 12 -100	Day 1	Day 12 -100	Day 1	Day 12 -100
Fresh water	-1.38×10^{-1}	5×10^{-3}	-0.65×10^{-1}	-3×10^{-3}	-0.52×10^{-1}	-1.5×10^{-4}
Sea water	-2.8×10^{-1}	7×10^{-3}	-196×10^{-1}	-4×10^{-3}	-60×10^{-1}	-1×10^{-4}

The modelled fluxes for the mesocosms of Hicks et al. (2009) were compared to measurements conducted in these mesocosm experiments conducted by and found to give similar results (Table 1). The advective velocities were estimated from measurements by Hicks et al. (2009) of the infiltration of water into the sediments.

These results indicate that fluxes modelled using eqn (1) are similar to those measured. The modelling was performed using molecular diffusion for dispersivity of the solutes. The reason that such good results were obtained with just molecular diffusion is that the drying out of the lakes and acidity had killed almost all the benthic organisms (Baring et al. 2008). These results indicated that for Lake Alexandrina, the alkalinity of this lake could easily cope with this acid flux but for Lake Albert, the acid flux would be close to the alkalinity supply of the lake waters.

Keywords: *Sediment solute fluxes, Lower Lakes, modelling, water quality*

A 3D hydrodynamic-biogeochemical model for assessing artificial oxygenation in a riverine salt-wedge estuary

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Abstract: The presence of anoxia and hypoxia in bottom waters is regularly observed in salt wedge riverine estuaries. The extent of oxygen depletion depends both on physical circulation patterns and biogeochemical processes such as organic matter mineralization, photosynthesis and sediment oxygen demand. Over the past decade, reduced flows in the Swan-Avon River catchments have led to reduced flushing of nutrients and organic matter in the Swan-Canning estuarine system in Western Australia (WA), and more intense stratification that has been able to penetrate further upstream. As a result, hypoxia and anoxia in the upper reaches is a now a persistent management challenge due to detrimental effects on estuarine biodiversity and overall amenity and health of the river. As part of a multi-pronged strategy to tackle the problem of eutrophication in the estuary, several oxygenation plants have been installed in the upper reaches of the river that use micro-diffusers to re-oxygenate anoxic and hypoxic waters.

In this study we have aimed to simulate oxygen dynamics and assess the overall efficiency of the oxygenation plants through development of a finite volume coupled hydrodynamic – bio-geochemical model of the Upper Swan estuary (Figure 1). The model accurately captured the salt-wedge dynamics and extent and severity of hypoxia and anoxia. The model has been used to explore budgets of oxygen and nutrients for different plant operational regimes, and has allowed us to define the spatio-temporal benefit of these scenarios. The results are used to inform the most cost effective way to achieve the desired improvements in river habitat.

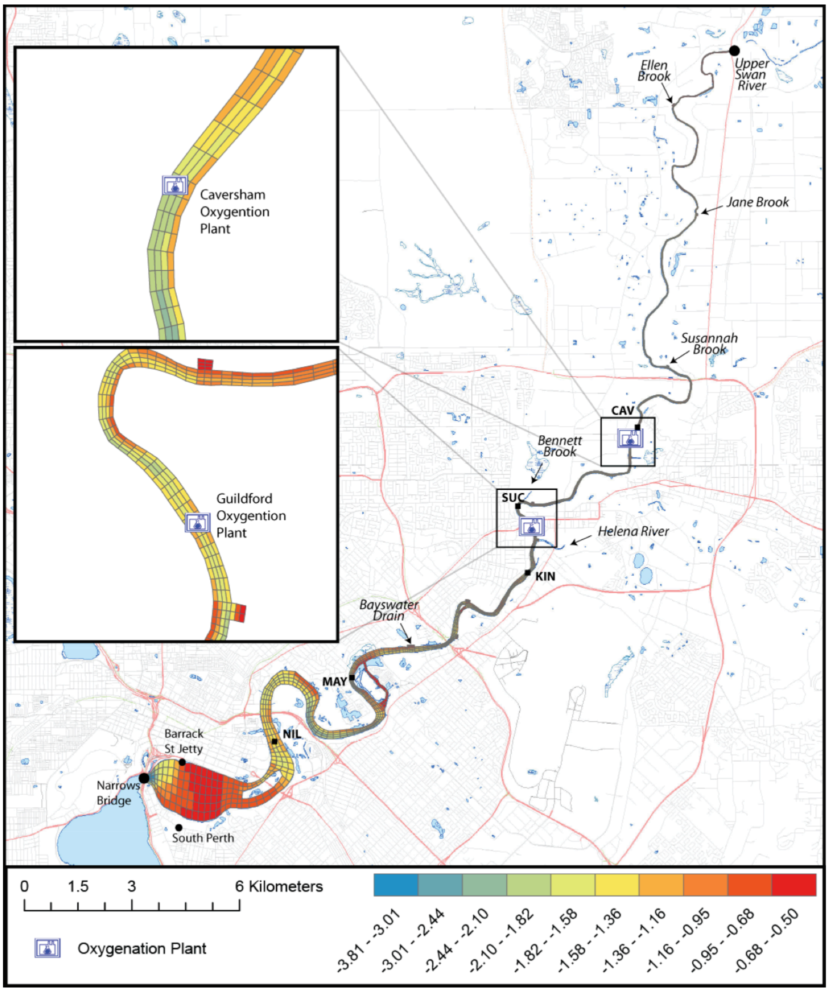

Figure 1. Upper Swan estuary computational mesh from Narrows Bridge the to Gt Northern Hwy Bridge, with two zoom regions shown near the Guildford and Caversham oxygenation plants, river inflow locations, and validation points. Colour scale indicates depth (mAHD).

Keywords: *oxygenation Swan-Canning estuary, sediment oxygen demand, river restoration*

Sediment-water oxygen and nutrient fluxes in a hypoxic estuary

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Abstract: Examining sediment-water fluxes can be essential for understanding aquatic chemistry and ecosystems, but the numerous coupled processes near the sediment-water interface make this a difficult system to analyse. This is especially pertinent in periodically hypoxic, nutrient-rich waterways, where the sediment oxygen demand and rates of sediment nutrient flux interact with the water column chemistry and ecology. In this paper, a region of the seasonally-hypoxic Swan River estuary in Perth, Western Australia, is examined to determine nutrient fluxes and the effect of oscillating bottom water oxygen conditions. The oxygen fluctuations investigated are designed to capture variability on seasonal scales as well as with high frequency (daily) changes in water column oxygen concentrations due to pumping by an oxygenation plant.

A numerical sediment diagenesis model is used to examine the system under natural and pumping conditions. The model is validated against available datasets of porewater depth profiles and fluxes of NH_4^+, NO_3^- and dissolved inorganic carbon. The simulated flux of NH_4^+ is found to be 16.3 mmol N d^{-1}. The peak flux of PO_4^{3-} corresponds to the period of anoxia. The depth of oxygen penetration into the sediment is between 1 and 1.5 mm, which shows little variation between oxic and anoxic bottom water conditions. It was found that there was limited time lag between the bottom water oxygen concentration and the sediment porewater concentration and therefore the sediment oxygen demand was largely insensitive to antecedent conditions. The model was used to develop a simple oxygen flux relationship for use in water quality models of the area. Areas for improvement of the model include the need for refining the timescale of oxygen fluctuation to capture the effects of changes shorter than one day; specifying separate organic matter rate constants for different reaction pathways; changing the effects of bioturbation and bioirrigation to reflect hypoxic environments; and including the effects of feedbacks into the water column, which can next be achieved by coupling this sediment model with a pelagic hydrodynamic and ecosystem model.

Keywords: *Dynamic sediment diagenesis model, hypoxia, Swan River Estuary, oxygenation*

A systematic review of the treatment of phosphorus in biogeochemical and ecological models

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Abstract: Aquatic biogeochemical and ecological models have become increasingly detailed, both in resolution and in the number of processes and components represented. It is timely to pause and take stock of these models. Do these models accurately reflect our current understanding of the biogeochemistry of aquatic systems? Is their predictive performance improving? Are they improving in the range of system properties and behaviours that can be predicted? Where there is variety in approaches or algorithms, can we demonstrate that one method is better than another and should be preferred? This review begins this process, focusing on how phosphorus cycles are represented in models of aquatic systems.

A systematic review of 71 distinct published biogeochemical and ecological models of aquatic systems in 167 applications finds:

- Lake models and marine models are very similar, while river and catchment models differ. This appears largely to be due to different traditions within modelling communities rather than real differences in biogeochemical processes.
- River models tend to have simpler representations of phosphorus than lake or marine models.
- The performance of river models is usually quantitatively assessed using standard metrics (77% of publications include some performance metrics), while this is usually not the case for lake models (35% include some quantitative metric) or marine models (only 29%).
- Across all three domains, models are becoming more complex over time (**Figure 1**), but there is no clear evidence that this is improving the predictive performance of models.

The appropriate degree of model complexity depends on a number of factors, including the resources and data available to support the model and the purpose for which the model is being developed. Simpler models can be more rigorously calibrated and evaluated and may have just as much predictive capacity, while physiologically-based models, which are usually more complex, may be more generalisable and better able to anticipate unexpected responses and emergent properties of the system.

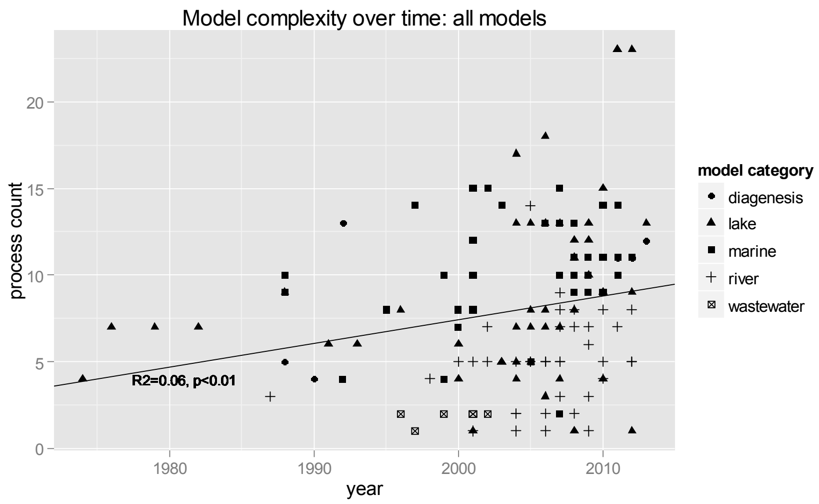

Figure 1 Model complexity over time.

A range of phosphorus papers not included in current models is discussed, including the biogeochemistry of organic phosphorus, the bio-geochemical implications of flow through sediments, and sediment drying and re-wetting. In some aquatic environments, these processes are likely to be important. It is concluded that a broader community toolkit of model algorithms is required.

Keywords: *Complexity, model assessment, modelling communities, ecological models, water quality, biogeochemistry*

Comparison of Reanalysis Datasets for Regional Climate Modelling

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Abstract: Although a lot has been done on comparisons of observational datasets and reanalysis at both global and regional scales, the usefulness of the comparisons to choose which reanalysis datasets to use for regional climate studies especially for initializing and setting lateral boundary conditions has been limited. Climate reanalysis is a climate or weather simulation of the past in which observations are assimilated into the model within the constraints of the physical laws of physics and time evolution. Setting of boundary conditions entails using the best global climate simulations to initialize and smoothen large climate scale features transition into a smaller and physically defined domain(area) of interest making sure that the climate features of the smaller domain are not 'isolated' from the global climate patterns. Comparisons have mostly been based on coarse resolutions of monthly aggregations and mostly at the surface and thus not helpful in giving insight information on details of consistencies or lack of provided by the reanalyses within the whole climate layer. It is against this background that this paper attempts to compare and evaluate relevance of different reanalysis datasets by comparing their selected finer temporal resolution (daily) hydro-climatological variables products (temperature and relative humidity) using both land and ocean based observational data over the domain 0 to 40 ^{0}S and 6 to 53 ^{0}E, covering Africa from the equator south-wards including Madagascar. The study domain is as shown by Figure 1 below.

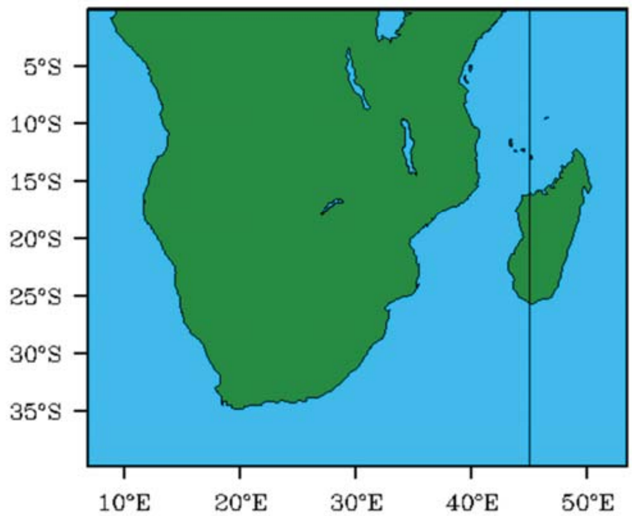

Figure 1. The study area (domain) of the research

Evaluations of the reanalyses will be made at 3x3 degree grids along the four (4) boundaries of the domain. The 3x3 degree grid is proposed to accommodate different reanalyses grids. The AIRS satellite data (1x1 degree resolution) is being used as observational data from which reanalyses data (relative humidity and temperature) will be compared. The reanalyses data will be interpolated to 1x1 degree grid resolution of atmospheric Infrared Sounder (AIRS) satellite data and 12 vertical levels. Efficiency terms including Root Mean Squared Error (RMSE), Bias, and Correlation Coefficients at different levels will be used to evaluate the reanalyses. Plots for comparisons across the vertical levels will also be attempted for consistency of the individual reanalyses. It is anticipated that the study will make a contribution as one of the very few fine-resolution regional climate modelling targeted reanalysis evaluation.

Keywords: *Reanalysis, Regional Climate Modelling, Comparisons*

Wetland vegetation – hydrology co-evolution in response to rainfall variability

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Abstract: Nonlinear interactions between physical, chemical and biological factors determine the spatio-temporal extent of flooding, the level of salinisation and the vegetation dynamics in wetlands subjected to a certain climate signal. These interactions were studied using an ecohydrological model of a wetland in a semi-arid climate designed to account for the tolerance of vegetation functional groups to salinity and water availability. In particular, the model represents *Melaleuca strobophylla* and *Casuarina obesa*, as well as terrestrial short-rooted grasses, to represent those typically found in Lake Toolibin, a Ramsar appointed wetland of south-west Western Australian (SWWA).

In a previous study, the model showed a good agreement when compared against available field data from Lake Toolibin. In this study, we explored specifically how variability in rainfall delivery can affect salt mobilization and subsequent vegetation abundance and assemblage. In order to test this, the model was tested under a range of rainfall intra-annual distribution with the same annual depth. Being particularly interested in semi-arid regions, the rainfall realisations were synthetically generated by a model previously calibrated to represent the precipitation typical of SWWA.

The model demonstrated the co-evolution between hydrology and vegetation, as well as the non-linear responses of vegetation dynamics to climate forcing, both being strongly influenced by salinisation. A higher rainfall intensity enhanced runoff, raised the water table level and decreased salt leaching, intensifying accumulation of salt in the root zone. This altered salt mobilization affected vegetation abundance, water uptake and significantly changed to the vegetation assemblage. The short-rooted, terrestrial-adapted *C. obesa* benefited from a rainfall signal that was more evenly distributed over the year, while *M. strobophylla* benefited from more intense rainfall events that cause water to pond for prolonged periods. This exercise highlighted the fact that salinity amplifies the impact of climate variability, significantly affecting both the overall vegetation density and assemblage. This fact reinforces the need to include salinisation processes within ecohydrological models used to study vegetation dynamics in semi-arid regions.

Keywords: *salinisation, wetlands, ecohydrological model, vegetation, Lake Toolibin*

Multiple Steady States and Regime Shifts in a Social-Ecological System

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Abstract: Traditional models of natural resources in ecology treat human activity, such as nutrient input or resource extraction, primarily as a driver of resource dynamics. The state of the resource, however, can of course feed back to affect human behaviour, leading to a coupling of human behaviour and resource dynamics in what is commonly called a *social-ecological system*. Here, to better understand the possible consequences of such social-ecological feedbacks, we explore a stylised model of a community of harvesters extracting a renewable resource, such as water in an irrigation system. We analyse the model to determine whether it can experience sudden and hard-to-reverse transitions, known as regime shifts, towards alternative stable states.

In the model, the amount R of a renewable resource changes over time according to

$$\frac{dR}{dt} = c - D(R) - Q(E(f_c), R),$$

where c is the (constant) resource inflow or growth rate, $D(R)$ is the natural resource outflow rate or mortality, and Q is the resource extraction. We model the social dynamics of co-operation amongst harvesters using the replicator equation from evolutionary game theory:

$$\frac{df_c}{dt} = f_c(1 - f_c)\left(-F(E(f_c), R) + W + \omega(f_c)\right),$$

where f_c is the fraction of co-operators in the population, $E(f_c)$ is the total effort exerted by the harvesters (which decreases with increasing proportion of co-operators), $F(E, R) > 0$ and W are the differences between the incomes and costs, respectively, received by a defector and a co-operator, and $\omega(f_c)$ represents the decrease in a defector's utility due to a social ostracism process by which co-operators, if there are enough of them, encourage defectors to co-operate (for example by refusing loan of machinery or transportation to market).

The above equations constitute our social-ecological model in generalised form. We analysed regime shifts in this model in two ways. First, we used the approach of generalised modelling to allow us to search for fold bifurcations (which can lead to regime shifts) in the model without needing to specify forms for the processes (functions) in the model. Second, we assigned specific functional forms to the processes and numerically computed bifurcation diagrams.

We found that multiple stable states and regime shifts occur frequently in models of the above structure and are robust to changes in the formulation of the model. Multiple steady states can even emerge in this system when none exist in the decoupled resource dynamics (where human behaviour is treated only as a driver onto the ecological), leading us to emphasise the importance of modelling the coupled social-ecological system. Furthermore, regime shifts in the social-ecological system had as dramatic consequences for the resource and its users as a conventional purely ecological regime shift. Somewhat counter-intuitively, however, in this model regime shifts leading to a break-down of co-operation were triggered by *increasing* resource availability. Finally, we also showed that standard ecological early warning signals may indeed also work for regime shifts in a coupled social-ecological system.

This work is also in press with the Journal of Theoretical Ecology:
http://link.springer.com/article/10.1007/s12080-013-0187-3

Keywords: *Regime shifts, tipping points, early warning signals, generalised modelling, social-ecological system*

The importance of model structural complexity when simulating aquatic food webs

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Abstract: The problem of simulating microbial interactions in aquatic systems is receiving considerable attention and has resulted in recent advances to ecological models for understanding and forecasting algal blooms. However, these ecological models often simplify microbial diversity and do not always provide an accurate picture of the nutrient flux pathways that occur in food webs due to the complicated nature of microbial interactions. This study used the FABM (Framework for Aquatic Ecosystem Models) framework to develop three ecological models of different structural complexity, that sequentially build on the classic 'Nutrient-Phytoplankton-Zooplankton-Detritus' (NPZD) model, to better understand the significance of specific microbial interactions ecosystem dynamics, namely the 'microbial loop' and 'viral shunt' (Figure 1).

The results of a 'Nutrient-Phytoplankton-Zooplankton-Detritus+Viruses' (NPZD+V) model were used to compare the influence of zooplankton mediated mortality relative to virus mediated mortality of phytoplankton. The results showed that virus mediated mortality via infection and lysis of phytoplankton can be as important as zooplankton mediated mortality via grazing under typical conditions. Next the results of the 'Nutrient-Phytoplankton-Zooplankton-Detritus+Viruses+Bacteria' (NPZD+VB) model indicated that the viral shunt can short circuit the microbial loop via viral infection and lysis of phytoplankton and bacteria, and thereby increase the transfer of material to the detrital pool. Furthermore, the more complex model structure that include the viral shunt and microbial loop pathways illustrated the importance of 'bottom-up' (resource) control of algal production via microbial interactions in aquatic ecosystems. These results help provide an improved mechanistic understanding for viral-bacterial-phytoplankton-zooplankton interactions in aquatic ecosystems and can help to guide decisions about appropriate model conceptualisations that can be used. Further work on systems analysis of the model structures is required to better understand their resilience and stable states that are likely to form under a range of nutrient enrichment conditions.

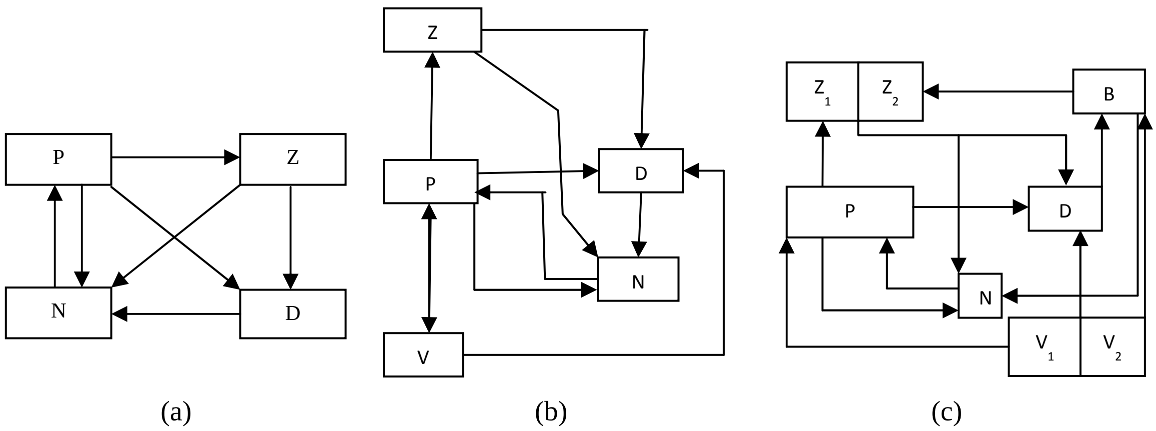

Figure 1 Structure of a) NPZD, b) NPZD+V, and c) NPZD+VB models (Note that Z_1 refers to normal zooplankton; Z_2 refers to the microzooplankton; V_1 refers to the phytoplankton viruses; V_2 refers to the bacteria viruses).

Keywords: *aquatic ecosystem; viral shunt; algal blooms; microbial loop; ecological modelling*

The emergence and existence of multiple hydrological steady states under stochastic climate forcing

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Abstract: The vast majority of hydrogeological modelling has implicitly assumed only one steady state can exist. However, recent work has shown that including positive feedbacks in hydrological models can result in complex behaviour with multiple steady states (henceforth, *attractor*) from a single parameter set. This paper summarises three of our recent *Water Resources Research* papers where a positive feedback arises from vegetation-aquifer interaction. Using a synthetic hillslope Boussinesq model, it is demonstrated that this feedback can give rise to multiple attractors for the same climate forcing and catchment parameterisation. Previous work had quantified the depth to water table of the attractors under monthly climate forcing using limit-cycle continuation. However, catchment runoff and recharge are nonlinear processes and are not adequately simulated at a monthly time scale; and hence the findings of multiple hydrological attractors are uncertain. To address this, a climate scaling limit-cycle continuation approach was developed to quantify the existence of attractors under daily climate forcing. It was applied for a range of aquifer hydraulic conductivity values and multiple attractors were found to exist under daily forcing. However, under daily forcing, multiple attractors existed for a smaller range of conductivity values (Figure 1). This indicates fewer saline catchments may have multiple attractors than previously estimated.

The existence of multiple attractors is, however, no guarantee that a catchment can switch between them. While a switch was dependent upon the stochastic forcing, contrary to previous resilience studies, the switch occurred without the catchment crossing the threshold between the attractors (henceforth, *repellor*). It occurred by an extreme climate event causing the loss of the current attractor (Figure 2). If the forcing event persisted then the system moved to the alternate attractor basin. Once the forcing event finished, then the original attractor re-emerged but the system persisted within the alternate attractor basin. By this mechanism, multiple hydrological attractors did emerge under daily forcing. However, the emergence of multiple attractors was significantly more complex than indicated by simply identifying the existence of attractors. For example, multiple attractors existed that did not emerge and temporary attractors emerged during wet periods that did not exist under average forcing. For these reasons, the resilience to climatic disturbances should be estimated by the stochastic forcing required to cause the loss of the current attractor, rather than by the standard measure of resilience (i.e. the state-space distance from an attractor to a repellor).

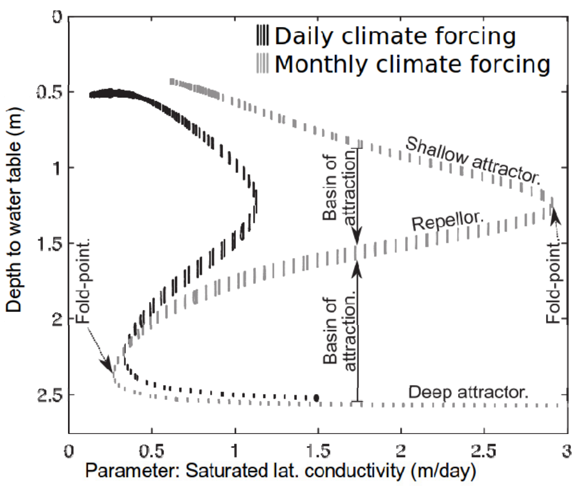

Figure 1. Depth to water table of attractors against aquifer conductivity under daily and monthly climate.

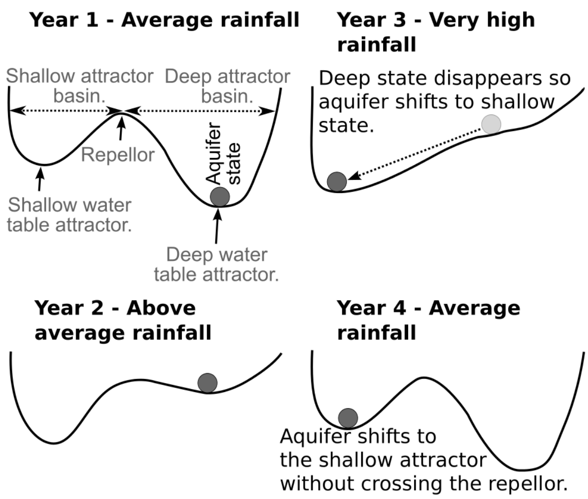

Figure 2. How stochastic forcing causes a change of attractor basins without the crossing the repellor.

Keywords: *Resilience, hydrological attractors, positive feedbacks, eco-hydrology, stochastic forcing*

The hydrologic implications of the co-evolution of forests, fire regimes and soil profiles in SE Australian uplands

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Abstract: Soils, vegetation, and fire regimes in the south eastern Australian uplands have evolved together over long timescales. The current observed biophysical states (interlinked combinations of soil, fire regime and vegetation) are therefore a product of a given set of climatic (radiation and precipitation) and geologic (geology, topography) conditions. Observation and measurement shows that these biophysical states are associated with strongly contrasting hydro-geomorphic characteristics, such as water yield, water quality, soil erosion, and peak flow behavior. A schematic of the relationship between the forcing variables, the biophysical state, and the hydro-geomorphic characteristics is given in Figure 1.

For example, dry open woodlands are usually associated with shallow poorly developed soils and high fire frequencies. However most trees recover from fire by re-sprouting, and rates of fire mortality are low, so age-related water yield declines are uncommon. However due to the poor soil structure, erosion rates and water quality impacts can be very high.

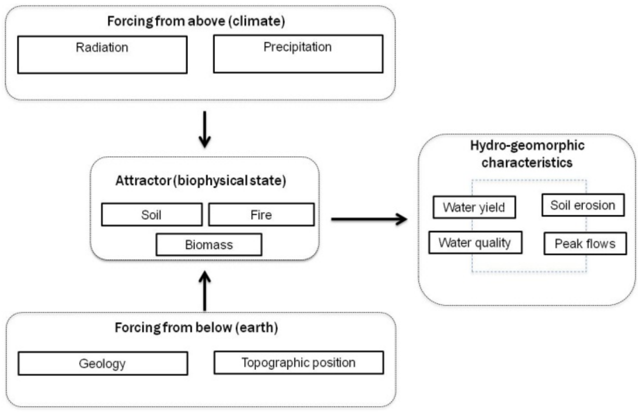

Figure 1. Soil properties, vegetation structure and the fire regime in south east Australian forests have evolved together in response to geologic and climatic forcing variables, resulting in forests with strongly contrasting hydro-geomorphic characteristics.

In contrast, tall wet forests are associated with deep, well structured soils, while fire frequencies are low as fuel moistures can remain high, even in summer. When fires do occur, they are intense and tree mortality can be high, resulting in even aged stands and yield declines at decadal timescales. However, due to the well structured soils, erosion rates and water quality impacts are relatively low.

Several decades of research has begun to describe these contrasting biophysical states and the associated hydro-geomorphic behavior. However, rapid changes in climate forcing due to accelerated climate change will likely result in a shift in these biophysical states towards some new state consistent with the altered forcing. In addition, individual components of the biophysical state are likely to have vastly different response times. For example, fire frequency could be expected to respond almost immediately to hotter, drier summers, while other properties such as soil depth and structure may take millennia to adjust to the new climatic forcing. As a result, we may experience "transitional states", combinations of fire, vegetation, and soils that do not currently exist.

What hydro-geomorphic behaviours should we expect from these new, transitional combinations? These may be difficult to predict, as local natural analogues may not exist. This presentation will draw on new data collected since 2003 from south east Australian forested uplands to explore the hydro-geomorphic implications of the co-evolution of forests, soils and fire regimes, in the context of changing climate.

Keywords: *Fire regimes, soil development, bushfire*

A framework for identifying and characterizing the supply and distribution of multiple ecosystem goods and services in multifunctional landscapes

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Abstract: Landscapes are multifunctional systems that satisfy a range of human needs by supplying different ecosystem goods and services (EGSs). We modify biophysical landscape components, i.e. land cover, to change the biophysical structure of landscapes and the range of benefits that flow from them. Spatial planning has a strong influence on how landscapes can accommodate human demands. Given the range of interests involved in land management practices and the great fluctuations in human demands on EGSs, maintaining the multifunctional nature of landscapes to deliver multiple EGSs should be a priority in decision-making processes.

Because spatial planning deals with allocating land uses, understanding the spatial aspects of multifunctionality is essential to effectively integrate the multifunctionality concept in planning. This research presents a GIS-based framework that identifies spatial characteristics of landscape multifunctionality. The framework highlights the applicability of GIS as a tool to better understand the multifunctional role of landscapes for planning and resource management. This framework supports spatial planning via three key steps. First, a spatial data set of seven EGSs is integrated to generate a spatial data layer of multifunctionality. To tackle the MAUP (Modifiable Areal Unit Problem) associated with the aggregation of spatial data and statistics, two different approaches are used: 1) a polygon-based approach using land units delineated with biophysical characteristics and, 2) a grid-based approach (250x250 metre cells). Second, a landscape zonation scheme (or classification) based on the number of EGSs, equally weighted, and the quality of landscapes supplying capacity at a single location, is developed to illustrate the variability of multifunctionality. Third, spatially explicit statistics and metrics provide a mechanism for interpreting this data. Hotspot analysis is used to identify areas with high and low concentrations of EGSs. Additional indices and metrics are used to quantify spatial patterns of multifunctionality distribution.

This framework is applied to the Coromandel-Bay of Plenty region, New Zealand. The resulting information offers valuable insights for identifying management issues by helping understand spatial aspects of landscape multifunctionality, the condition for the supplying capacity and planning possibilities. A zonation of landscapes based on multifunctionality supply helps visualize the distribution of such supplying capacity for multiple EGSs, pointing out the link between presence and quality of biophysical aspects of landscapes and their many contributions to society. Measurements provided by spatial indices help track changes on multifunctionality supply over time and space, providing useful information to guide the design of policies for the enhancement multifunctionality. The identification of spatial explicit features (i.e. areas with consistent concentrations of high, *hotspots*, and low, *coldspots*, values for multifunctionality assessments), as a result of the Hotspot analysis, is expected to help orient future research and management efforts. Overall, this work is expected to highlight research opportunities to advance the ecosystem services framework as an operational basis for an integrative element for regional management.

Keywords: *Ecosystem goods and services, GIS, multifunctional landscapes, planning, resource management*

Ecosystem services in environmental sustainability: a formalized approach using UML

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Abstract: Ecological systems generate diverse services that are vital for human well-being and socio-economic development. Ecosystem services are a key notion for the idea of sustainable environmental development. A practical utilization of this concept of sustainability requires a mechanism whereby all the goods and services generated by ecosystems are adequately quantified, valuated and incorporated in the decision-making process. Each of these tasks is substantially non-trivial. To deal with the named complexity, an adequate theoretical framework and a sophisticated information system have to be in place for the use by stakeholders of environmental sustainability.

A theoretical framework for environmental sustainable management and its further extension on the basis of a meta-modeling approach have been suggested in our prior publications. As the next step, we need to build an information system implementing the main elements of the framework in corresponding software components.

In this paper, we are suggesting a formalized approach to the entire process of sustainable environmental management on the basis of the Unified Modeling Language (UML). UML is a standardized graphical language being used in object-oriented software engineering for specifying, documenting and visual modeling of an IT project's artifacts or components within a wide range of applications. With the three groups of graphical models (i.e., functional, object and dynamic), UML is aimed to provide a standard notation and describe different aspects of a software project. We demonstrate the ways, in which UML can be applied in the information systems development for the needs of environmental management and protection. The constituting software blocks of an environmental information system implementing the framework are presented by the following UML graphical models:

- overall system architecture is depicted as a UML *package* diagram;
- contents of the `Ecosystem` package are shown as a UML *use-case* diagram;
- activities of the `Monitoring` package are shown in the notation of a UML *use-case* diagram
- the `Modeling` package is presented as a UML *component* diagram;
- internal steps within the `Modeling natural dynamics` module are shown as a UML *use-case* diagram;
- logic of the `Modeling anthropogenic dynamics` module is demonstrated as a UML *use-case* diagram;
- internal steps of the `Valuation` package are shown as a UML *use-case* diagram; and
- flow of operations within the `Management` package is presented as a UML *activity* diagram.

For many years, UML has been successfully utilized in the systems development life cycles of business-type IT projects. It is supported by multiple commercial and free CASE-tools, including those featuring reverse- and round-trip engineering.

At the same time, despite obvious advantages, applications of UML in the design of environmental information systems remain rather limited. While UML has not been widely adopted and used in environmental modeling and software design, it is reasonable to expect growing interest towards UML in the field as a tool to combine the power of visual and simulation modeling and to facilitate automated construction and synthesis of environmental information systems.

The paper is also intended to inspire and shape the discussion within the session on "Models, Methods, Techniques and Tools in Quantifying Ecosystem Services and Environmental Sustainability".

Keywords: *Environmental management, ecosystem services, Unified Modeling Language (UML)*

Application of a forest dynamics simulator to inform sustainable biodiversity conservation and grazing management in Australia

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Abstract: Sustainable use and management of natural resources is now a well-accepted principle, but its implementation continues to elude us. This is partly because of the complex and dynamic nature of ecological systems, interdependence among elements, and the impacts that resource management actions have on the functioning of an ecosystem.

Livestock grazing is the most extensive landuse in Australia, occurring in over 55% of the continent. In forested landscapes this landuse has been characterised by clearing and/or modification of landscapes through overgrazing and changes to fire regimes, followed by re-growth and increase in density of woody vegetation and associated loss in grazing productivity. Consequently, the Vegetation Management Act 1999, now in place in Queensland, requires the coexistence of conservation of biological diversity and primary production. However, a challenge exists in how to integrate the two outcomes in a sustainable manner.

This paper describes a case study application of the Ecosystem Dynamics Simulator (EDS), a forest growth model, as a decision support tool for the integration of sustainable livestock production and conservation of biological diversity at Mt Armour Nature Refuge, in western Queensland. The study was initiated by a request from the landowner for advice on how to manage increasing density of woody vegetation (vegetation thickening) without compromising conservation values.The landholder had expressed concern that the vegetation thickening was impinging on livestock production and was therefore in need of thinning. Thinning of vegetation within this bioregion is regulated by the Regional Vegetation Management Code for Brigalow Belt and New England Tablelands Bioregions, Queensland Government (Code) (DNRM, 2012). Firstly, for thinning to occur, the Code requires a verified crown cover increase or presence of > 250 immature stems in a 0.25 ha area. Secondly, if thinning occurs, all mature stems should be retained, and including 75 or 125 immature stems per 0.25 ha area depending on vegetation type.

Our objective was to establish: 1) whether density of immature stems met thinning criteria of the Code and; 2) what thinning intensity and fire regimes were necessary to promote a sustainable ecosystem. In examining thinning intensity, the potential risk of loss of biodiversity based on recommended retention rates was also investigated. Working in collaboration with the landholder, data were collected from the property and the landowner's tree removal preference was also recorded. The EDS was used to project long-term changes in tree species composition and diameter size class structure for the uneven-aged mixed species native forests and to explore management scenarios that included the use of alternative thinning scenarios and fire regimes.

The results confirmed: 1) the vegetation on the site was dense enough to be thinned under the current Code and projection indicated thickening is likely to continue if left un-thinned; 2) that the landowner's preferred tree removal intensity was not sustainable and; 3) a thinning intensity based on long-term simulation that considered species composition and stand size structure provided the best compromise outcome. The simulation results also confirmed likely inadequacy in the Code's recommended retention rates for immature stems in the studied vegetation types. Retaining only 75 immature stems (< 20 cm dbh) appeared to be a high risk option because large trees were few, growth rates were low and sapling recruitment was intermittent and vulnerable to drought related mortality. Consequently, retention of at least 140 immature stems would provide a more resilient stand structure and species composition under the dry growth conditions at the study site. This study demonstrated the valuable role that a vegetation growth dynamics simulator can play in elucidating long-term changes in tree species composition and diameter size structure in support of sustainable environmental management.

Keywords: *Decision support, vegetation thickening, sustainable thinning regime*

LUTO – Modeling outlooks for land use and ecosystem services in Australia

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Abstract: This century, the already-substantial competition for the Earth's finite land resources will continue to intensify. Human populations and lifestyle changes will increase demand on the land system for productive outputs such as food and fibre, urbanisation, mineral and energy resources, and a range of other ecosystem services. Climate change (1.4-5.8°C warming by 2100) will affect the ability of the land system to produce these and adaptation will be required. As a result, food, energy, and water security, in addition to critical declines in biodiversity, soils, and other natural resources, will become the key global challenges for humanity. Australia's unique land systems are especially vulnerable to these global challenges. Until now, Australia has had no capacity to explore the effect of external drivers on land use, nor to test the cost-effectiveness of domestic policy, planning, and governance responses.

Global environmental and economic trends, combined with changes in domestic policy may motivate the adoption of a range of land use and management options, particularly for climate change mitigation and adaptation. However, these changes in land use and management may generate collateral impacts. There is a need for the ex-ante evaluation of the impact of alternative global outlooks and domestic policy scenarios on land use and ecosystem services in Australia's agricultural landscapes. This information is required to inform decision-making for Australia's transition to a low carbon economy. We describe the Land Use Trade-offs (LUTO) model—part of CSIROs Australian National Outlook (ANO)—designed to explore futures for land use in Australia.

LUTO is an integrated environmental-economic model of land use in Australia's intensive agricultural zone out to 2050. LUTO itself integrates a range of distinct models of environmental and economic processes. Within the broader ANO, LUTO is loosely coupled to a range of other environmental and economic models—taking inputs from and providing outputs to them. Global economic (carbon price, food demand, oil price) and climatic trends are taken from the Global Integrated Assessment Model. LUTO itself is a high resolution partial equilibrium land use model. It allocates land uses including existing agriculture but also new land uses such as environmental plantings, carbon plantings, and a range of crops for bioenergy and biofuels feedstock at 1km grid cell resolution. A key input to the model are layers of profitability of each land use which are calculated each year given changes in productivity, price, and cost of production. Being a partial equilibrium model, as new land uses outcompete agriculture they reduce supply of agricultural commodities, thereby increasing the price. New land uses are allocated and agricultural commodity prices are solved for simultaneously in a mathematical programming model such that net social welfare (the sum of consumer and producer surplus) is maximized. Optionally, constraints (e.g. rates of reforestation) can be placed on land use change to assess the impact of capacity limitations. A biodiversity payment policy is assessed in this version which allocates an annual biodiversity budget for environmental plantings in high priority areas. A bioenergy policy is also assessed.

The implications of changes in global outlooks and domestic policy options on land use and the impacts across a range of ecosystem services including food and fibre production, carbon, water, energy, and biodiversity were significant. The impacts of land use change included complex co-benefits and trade-offs across multiple environmental, social and economic indicators. Substantial areas of agricultural land were subject to competition from new land uses that both mitigate and adapt to climate change. A global carbon price had a strong influence on the adoption of new land uses as is a domestic bioenergy policy. The results were sensitive to assumptions about agricultural productivity and adoption behavior. Livestock grazing was disproportionately targeted for land use change especially in areas such as southern Queensland which currently make low returns under extensive grazing but have the capacity to increase returns by an order of magnitude through reforestation and carbon sequestration. The exploration of alternative plausible futures for Australian land use can forewarn us of changing drivers and inform policy and institutional design to both capture the positive effects and avoid the negative ones.

Keywords: *Land use, scenarios, spatial, GIS, model, policy, conservation planning, ecosystem services*

Hydrological modelling of paired catchments with competing land uses

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Abstract: We report the preliminary results of a modelling study of surface/subsurface water interactions applied to a paired-catchment project that is primarily aimed at quantifying the hydrologic response of catchments with competing land uses. The study focuses on a site in southwestern Victoria, Australia, composed by two adjacent catchments with different agricultural uses (grazing and *Eucalyptus globulus* (blue gum) plantation), but similar topography, geology and soils. The grazing and plantation catchments have a size of 0.48 and 0.76 km^2, respectively, and their monitoring network comprises groundwater observation bores, stream gauges and a rainfall station.

We use the distributed, numerical model CATchment HYdrology (CATHY), which simulates flow in the surface, soil, and aquifer zones as well as the hydrological interactions across the atmosphere–land surface–subsurface continuum. CATHY combines a three-dimensional equation for subsurface flow in variably saturated porous media with a one-dimensional diffusion wave approximation of the de Saint-Venant equation for surface water dynamics. A particular feature of CATHY controls the switching between atmosphere-controlled and soil-limited evapotranspiration; the switching is regulated by a threshold pressure head (ψ_{min}) and is used in this study to investigate CATHY's capability to simulate the impact on water fluxes of different types of vegetation.

Preliminary simulation results of a 1-year period show that the model is capable to reproduce satisfactorily the hydrological regime of both catchments without the need for a detailed multiparameter calibration. In particular, the surface hydrological response is matched satisfactorily by the model simulations, with a reasonably good fit (Nash-Sutcliffe coefficients of 0.63 and 0.52 for the grazing and plantation catchments, respectively) in terms of daily flow hydrographs. Water table levels observed in the bores proved to be more difficult to match, even though the overall groundwater dynamics is well captured by the model.

The use of two different values of ψ_{min}, which control the conversion of potential evaporative demand into actual evapotranspiration, accounts for the impact of the different vegetation covers on the total water budget. The two threshold parameters will be accurately calibrated in the next step of this study by matching the simulated fluxes to measurements of actual evapotranspiration. The model will thus allow accurate quantification and comparison of the catchment scale impacts of different agricultural land uses on surface water and groundwater fluxes.

Keywords: *Surface/subsurface water interactions, paired catchments, hydrological response, evapotranspiration*

Use of Multi-Criteria Analysis Shell for Catchment Action Planning: Ecosystem Services and Threat Analysis approach

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Abstract: In NSW Catchment Management Authorities are required to produce natural resource management plans. They are encouraged to use a spatial resilience approach to determine types and locations of priority issues to be addressed. We identified areas with the highest soil ecosystem service values with the greatest immediate threat of becoming irreversibly damaged using the Multi-criteria Analysis Shell for Spatial Decision Support (MCAS-S) spatial modeling software. We used existing NSW soil, climate and land use data layers. The approach was piloted for the Hawkesbury Nepean Catchment Management Authority and later adopted by other CMAs across NSW.

MCAS-S software and existing NSW soil and land related spatial data layers were used to map the values of three key soil ecosystem services: clean water; primary productivity; and soil type dependant biodiversity.

The water quality ecosystem service used RUSLE modelling sheet erosion, assessment of nutrient sources and overland sediment transport processes. RUSLE modelling included 144 monthly MODIS ground cover time series, coupled with best available state-wide soil erodibility, 60 year daily time step rainfall erosivity and topographic data.

Most nutrients in soil are either associated with soil formation factors or added during land use. Soil nutrients are associated with small particles and it is the clay fraction which when eroded reaches water bodies. Soil erosion flux values were adjusted depending on the relative proportion of surface layer clay and dispersible fine fractions as well as surface layer nutrients according to soil type lookup values. A simple look up of added nutrients according to land use was also added. In effect the relative amount of fine particles and nutrients impacting water quality can be traced to individual pixels.

The soil productivity ecosystem service was based on Prescott for moisture availability, soil type for intrinsic fertility, additions of infrastructure and nutrients by land use and the impact of cold temperatures on growing season.

Soil biodiversity was modelled by intersecting land use values according to relative soil disturbance with soil types. Undisturbed pockets of soil types which have the largest amount of disturbed area have the highest biodiversity values.

The three soil ecosystem service values were then added to obtain ecosystem service priority maps.

We used rule based land and soil capability maps of various land degradation hazards (eg water erosion, wind erosion, acidification, soil structure decline, salinity) and compared them against available land management practice information. The relative impacts, or upper sustainable limits of individual land management practices (eg application of lime, burning stubble, cell grazing) where spatially compared against land and soil capability ratings. Large mismatches between land management limits and land capability can be expected increase the risk in rapid degradation. Where such mismatches occur where soil condition is close to an irreversible tipping point, eg total loss of topsoil, there is a significant threat to delivery of soil ecosystem services, eg productivity.

Threats were assessed by analysis of NSW soil condition monitoring data in conjunction with land management within capability information. Land that is in poor condition with unsustainable land management is land which is closest to first reaching an irreversible tipping point. Catchment action is most justified where such land also has large soil ecosystem service values.

MCAS-S is an excellent tool for catchment planning because of: model transparency; ability of stakeholders to readily examine the impact of changes in model weightings and ease of use for those with limited GIS experience.

Keywords: *Soil Ecosystem Services; threat analysis; water quality; land productivity; soil biodiversity; land management within capability*

The effects of climate change on ecologically relevant flow regimes: A comparative study between Upper Murrumbidgee and Goulburn Broken catchments

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Abstract: There is a wide scientific consensus that shifts in climate conditions may cause substantial changes to streamflow and water quality regimes. However, there is still limited understanding of the nature and magnitude of expected changes across Australian catchments. To build this understanding, climate change assessments need to move beyond basin-level assessment, and focus down on the river reach level so that findings are at appropriate scale to inform management initiatives. Comparing outcomes from multiple site-specific assessments will help paint a picture of “hotspots”, and identify drivers (e.g. land use) that may amplify or reduce expected impacts. In this paper, we present a comparison between findings from two assessments conducted for: Upper Murrumbidgee (in south eastern Australia) and Goulburn (in northern central Victoria). We used a suite of ecologically relevant hydrological indicators (i.e. Indicators of Hydrologic Alteration) to determine the significance of projected climate driven hydrological changes in both catchments.

Flow data were analysed for pre and post dam historic, and for thirty SEACI climate scenarios at a set of regulated and unregulated sites. To select the scenarios with the highest degrees of alteration, non-parametric statistics (median, 25th percentile and 75th percentile) for all indicators across scenarios were estimated. Pre-dam historical data set were considered as the baseline and absolute percentage change in the statistics for all scenarios with respect to the baseline were calculated. The absolute percentage changes then given a score using the following rule: 0 (if minor change, less than 30 %), 1 (if moderate change, 30–70 %), and 2 (if major change, greater than 70 %). For the selected stations on Goulburn, the scenarios CSIRO2, INMCM2 and Regulation observed maximum alteration in indicators. The same set of scenarios was showed maximum alterations in indicators in Upper Murrumbidgee. The scenarios, CSIRO1, CSIRO2, INMCM1, INMCM2 and Regulation were considered to select the indicators of hydrological alterations with major changes. Among the thirty three indicators, mean monthly flows in September, October and November; maximum of 1, 3 and 90 days flows; mean of high flow events and duration of high and low pulses showed maximum alterations. Non parametric Kendall’s Tau correlation coefficients were estimated to observe any significant correlation among the indicators. A set of seven indicators (mean monthly flows in September, October and November; maximum of 3 and 90 days flows; mean of high flow events; and duration of high pulses) were selected. However, in the Upper Murrumbidgee study, six indicators: mean monthly flows in February, mean monthly flows in March, 30-day Minima, frequency of high pulses, frequency of low pulses, and duration of low pulses showed maximum alterations.

While considering only the regulated sites, the CSIRO2 and regulated scenarios produced the largest change in indicators, however, the regulated scenario observes greater range of scores across the sites. Scenarios INMCM2 and CSIRO1 showed moderate hydrological alteration and INMCM1 showed minor to moderate change. For the scenario CSIRO2, the indicators mean monthly flows of September and October shows higher degrees of alteration with wider range of variation across stations. However, for the scenario ICMCM2, duration of high flow event shows maximum alterations and more variations in score across stations. Considering the catchments, Upper Murrumbidgee and Goulburn, the same set of scenarios were observed as showing maximum alterations in flow indicators. However different sets of indicators were found to have maximum alterations over the scenarios. Hence, different climate change scenarios are supposed to impact differently on various aspects (water quality, ecology etc.) of streamflows. The variations of the changes in the hydrological indicators across the flow stations should also be considered while taking any decision.

Keywords: *Climate change, Indicators of Hydrologic Alteration, Upper Murrumbidgee, Goulburn Broken*

Distributed Hydrological Modeling of a Monsoon Dominated River System in Central Vietnam

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Abstract: Vietnam is regarded as a country which is strongly impacted by climate change. Population and economic growth result in additional pressures on the ecosystems in the region. The water balance is stressed particularly by the construction and operation of hydropower dams, urbanization, and increasing demands for water by its industries and inhabitants. The Vu Gia-Thu Bon watershed catchment located in central Vietnam, impacted by a tropical monsoon climate and with an area of 12,000 km². In order to assess the impacts of climate and land-use changes, the distributed hydrological model J2000 was used to simulate the water balance of this catchment. J2000 incorporates the various hydrological processes and is available through the JAMS (Jena Adaptable Modeling System) modeling framework developed at the University of Jena. Due to the lack of measurement data, parameter transfers were performed from one sub-catchment to the entire catchment area. The results and statistical objective functions indicate that the model and the parameter transfers are able to simulate adequately the hydrological system of the catchment. In the next step the distributed model results are used by hydro dynamic models (Mike 11 and Mike Flood) and Mike Basin, all developed and supported by the Danish Hydraulic Institute (DHI). Although Mike-11 and Mike Flood simulate flood and saltwater intrusion dynamics in the rivers, Mike Basin is used to estimate the effects of actual and proposed hydropower facilities and other hydrological infrastructure.

For projecting future climate-change, results of WRF (Weather Research and Forecasting) downscale simulation will be used. Also, various scenarios of land-use change will be used to project future development in the catchment area. The results of the J2000 simulation will provide national and local stakeholders with information for decision support in land-use and hydrological-management issues.

Keywords: *Distributed hydrological modeling, model coupling, parameter transfer, central Vietnam*

Quantifying impacts of agro-industrial expansion in Mato Grosso, Brazil, on watershed hydrology using the Soil and Water Assessment Tool (SWAT) model

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Abstract

***Problem Statement*:** Dynamically changing Land Use and Land Cover (LULC) in the tropics may significantly affect catchment hydrology with implications for the management of river basins. It is, however, unclear how future changes will impact water related ecosystem services. The results presented in this study are part of the CarBioCial project in Southern Amazonia which aims at monitoring and quantifying catchment water balances and associated carbon cycling within a dynamic landscape context. Based on predictive modeling the project also aims to investigate how far changes in climatic regimes and LULC can impact the provision of water related ecosystem services such as water quantity, quality, and distribution as well as carbon storage and sequestration at the local and regional level. The methods and results presented in this paper are a preliminary investigatory assessment of the inter-relationship between LULC and catchment hydrology.
Approach: We apply the Soil & Water Assessment Tool (SWAT) model, to evaluate hydrological responses for different LULC change scenarios (deforestation, cropland, cerrado and pasture expansion) in the Rio Das Mortes watershed in Mato Grosso, Brazil. General input data such as topography, soil and land use data were used to run SWAT and the model was calibrated and validated using discharge data measured at two gauging stations in the watershed. The Sequential Uncertainty Fitting (SUFI-2) algorithm in SWAT-CUP was used for model calibration and validation. To assess the impacts of land cover changes on watershed hydrology, the calibrated model was applied to scenarios of LULC within this watershed. Results of water balance simulations are presented taking into account the effects of different rainfall patterns.
***Results*:** Generally, the model performed satisfactorily, indicated by values greater than 0.75 for Nash-Sutcliffe (NS) and the coefficient of determination (R^2) for two gauging stations in the study watershed during the calibration period (1986-1995). For selected likely future land cover scenarios including conversion of pasture to cropland, simulation results showed that land use changes result in corresponding increases in surface runoff and water yield (4-8%) and decreases in evapotranspiration, soil water infiltration and base flow (5-13%). Increased water yields however are not sustained in the dry season as shown in the flow duration curves. The results indicate that land cover changes to agriculture activities is likely to reduce dry season flows and increase peak flows in the wet season. Reduced dry season flows may lead to greater water scarcity at critical times of the year while increased peak flows may lead to enhanced soil erosion and thus impact on water revision in the watershed.
***Conclusions*:** This research has successfully utilized the semi distributed SWAT model to evaluate how catchment hydrologic fluxes including water yield might be impacted by anthropogenic changes associated with LULC dynamics. Future work includes applying the calibrated model in different long term climatic scenarios and also to use the model for prediction in ungauged catchments by applying it to a meso-scale catchment within the study watershed where there are no discharge data available for model calibration. This multi-scale approach will be used as it allows quantification of scale-specific signatures for the simulation of land management induced changes in water balance components at a local scale.

Keywords*: Land Use Land Cover Change, Watershed Hydrological Response, Alternative Scenarios, SWAT model*

Sensitivity of land-use pattern optimisation to variation in input data and constraints

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Abstract: Spatial optimisation has been widely used in scientific studies for land-use pattern optimisation and resource allocation, often to maximise ecosystem services and/or land use performances. Such use implies its applicability in real-world spatial planning and policy development. But how suitable is spatial optimisation, especially in the context of uncertain input data and stakeholder expectations? For example, what is the impact of uncertainty associated with modelled nitrate leaching rates on land-use pattern optimisation with the objective to minimise nitrate leaching? Since spatial optimisation problems are usually constrained by stakeholder expectations or preferences, it is equally important to know how sensitive optimal land-use pattern are to changes in those expectations and preferences.

In this paper, we investigate how sensitive optimal land-use patterns are to variation in input data (e.g. nitrate leaching rates) and optimisation constraints, such as stakeholder expectations in terms of agricultural production outputs. Our analysis was based on a spatial optimisation study in the Hawke's Bay area of New Zealand's North Island. The objective was to explore the landscape's limits in terms of the potential reduction in nitrate leaching. The optimisation problem was constrained by expectations for agricultural production outputs of the main agricultural land uses in this area. The spatial optimisation was based on nitrate leaching rates for each land use-land parcel combination of the case study area. Since no information was available on the uncertainties associated with the given nitrate leaching rates, we computed seven different optimisation scenarios, assuming seven different levels of uncertainties ranging from 5% to 50%. For each of those seven scenarios, we computed 500 optimisation runs and added to each run a uniformly distributed random error to the given nitrate leaching values. We then determined the allocation frequency of each land use to each land parcel for each uncertainty level. Based on the allocation frequencies, we determined the maximum allocation probability for each land parcel and uncertainty level, which represents the most likely allocated land use over 500 optimisation runs. The distributions of allocation probabilities across land parcels as well as across uncertainty levels were then used to characterise the sensitivity of the optimal land-use pattern to variation in the underlying nitrate leaching rates. To compare the landscape's potential to reduce nitrate leaching across the different uncertainty levels, we calculated the mean total nitrate leaching for the case study area for each uncertainty level (i.e. across 500 optimisation runs) and associated it with the mean maximum allocation probability for the particular uncertainty level. To analyse the impact of variation in the optimisation constraints on the optimal land-use pattern, we followed a similar approach. But instead of a random perturbation like with the nitrate leaching rates, we systematically varied the optimisation constraints by values ranging from +50% to –50% to compute a total of 14 different optimisation scenarios. However, only nine scenarios with values ranging from +10 to –50% actually represented feasible optimisation problems and yielded an optimal land-use configuration. To characterise the variation in the generated optimal land-use pattern, we also derived allocation probabilities, which referred to the nine feasible optimisation scenarios featuring different optimisation constraints.

The results of the optimisation scenarios show that the potential reduction of total nitrate leaching increases with the uncertainty of the modelled nitrate leaching rates. Hence, the spatial optimisation potential increases with the variance of the input data. The mean maximum allocation probability decreased with higher uncertainty of the input data. The observed sensitivity of the land-use configuration to variation of the optimisation constraints is in general smaller than the observed sensitivity for the variation of input data. Uncertainty of input performance scores for spatial optimisation can lead to an overestimation of the actual benefit of spatial optimisation. In the Heretaunga case study area the potential spatial optimisation benefit was overestimated by more than 5% points for uncertainty levels of more than 20%. Uncertainty associated with the optimisation performance scores had overall greater impact on the uncertainty of optimal land-use allocation than the variation of optimisation constraints. Maps of maximum allocation probabilities help spatial planners identify hot spot areas for targeted land-use development and change.

Keywords: *Land-use pattern, Sensitivity, Spatial optimisation, Allocation probability, LUMASS*

Multi-objective spatial optimization for integrated agricultural climate change adaptation

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Abstract: Climate change can have various impacts on agroecosystems. Crop production could increase or decrease depending on crop type and management, and depending on the extent of climate change relative to current conditions. Likewise, other functions such as soil or groundwater protection could be affected either positively or negatively. Since crop management is a major driver of all agroecosystem functions besides climate, there is scope for adaptation to climate change. In this study, we apply multi-objective spatial optimization to explore possibilities for adaptation of crop and land management with respect to multiple agroecosystem functions across a meso-scale catchment in Western Switzerland. The optimization approach integrates a generic crop model (CropSyst) calibrated for the main crops grown in Switzerland in combination with a simple livestock model relating requirements of livestock production to fodder production derived from the crop model. The evaluation model framework is first applied to quantify impacts of climate change on agricultural productivity, soil loss, leaching and irrigation water use for the time horizon 2036-2065. For identifying optimum possibilities for management adaptations for this time horizon, spatial optimization is applied with the goal function to maximize scaled yields, while minimizing soil loss, nitrate leaching and water consumption for irrigation. Weights for the different objectives are systematically varied to sample the four-dimensional pareto front of optimum trade-offs between the four objectives. Self-organizing maps are used to visualize and explore the trade-offs. For further and more detailed analysis, specific solutions are selected.

The approach is applied in an agricultural case study region in Western Switzerland, where irrigation is already common agricultural practice under current climatic conditions and limited water availability for irrigation has been a problem in extremely dry years in the past.

Our model results for the case study region suggest that with climate change, crop production may decrease, while soil loss and nutrient leaching increase if no adaptation measures are taken. Optimization results suggest that there is a wide scope for mitigating these negative impacts of climate change on different functions of the agroecosystem in the study region through changes in crop choice, irrigation, fertilization and soil management. However, changes in favour of one function can negatively affect other functions, and our results suggest that such trade-offs between agroecosystem functions can aggravate under climate change. From the multitude of optimum trade-off solutions, balanced adaptation options are selected, which could provide guidance for regional planners for the development of integrated adaptation strategies. The recommendations for management adaptations include (i) reduced soil management to reduce nitrate leaching, (ii) increased proportion of grassland to reduce soil loss and enhance organic matter and nitrogen availability in the soil for subsequent crops in the rotation, (iii) reduced proportion of irrigated spring crops in favor of non-irrigated winter crops, and (iv) increased irrigation to reduce production risks of high-yield crops.

Keywords: *Agroecosystem functions, climate change, adaptation, multi-objective optimization*

Identifying trade-offs of increasing biogas crop production in a German watershed under climate change

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Abstract: Political agendas worldwide include increased production of biofuel. The existence of trade-offs between increasing biofuel crop production and several conflicting objectives, such as food and fodder production, water quantity, water quality, biodiversity and ecosystem services, is well known. However, the quantification of these trade-offs is typically based on the comparison of a limited number of plausible alternatives. We extended the analysis by applying a multi-objective genetic algorithm to estimate the set of Pareto optimal solutions which describes the trade-offs between the objectives. For each solution at the Pareto frontier, no solution can be found that would increase one objective without decreasing another objective. They represent the (estimated) best options given the model and the specified control options. Our analysis was based on two alternative biogas crop production schemes: a corn based production scheme and a two-culture production scheme. The integrated river basin model SWAT was used to evaluate the effects of the different production schemes on bioenergy crop production, food and fodder crop production, water quality and low flow discharge. These four objectives had been identified together with local stakeholders. We started by defining crop rotation schemes that reflect the current land use in the case study region, a medium sized agricultural watershed (~320 sqkm) in Central Germany, the Parthe watershed. Based on that set of crop rotation schemes we defined two additional sets of crop rotations that either included an increase in corn in the crop rotation or an adaptation of the two-culture system. We run the optimization algorithm for combinations of the three sets of crop rotations to identify the trade-offs involved in biogas production by corn, by the two-culture system or by a combined approach that selects from all three crop rotation sets. We focused on agricultural land use modifications: forest, grassland, urban areas and wetlands were not modified during the analysis. The two biogas crop rotation schemes showed significant differences in their trade-offs with water quality and low flow conditions. Expectedly, the combination of all three crop rotation sets allowed greater flexibility and outperformed therefore the solutions achievable by focusing on one biogas crop rotation set. To assess the robustness of the solutions, we compared trade-offs under current climate conditions with trade-offs under two different regional climate scenarios. The estimated trade-offs differed significantly under the different climate condition, highlighting thereby that trade-off analysis has to consider changing boundary conditions.

Keywords: *River basin management, Ecosystem Services, trade-offs, water quality, bioenergy, land use, optimization, crop rotation schemes*

Habitat modelling: A multi-models approach to map the potential distribution of alpine vegetation assemblages in France

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Abstract: This paper presents a method to assess the potential distribution of alpine species assemblages in the crystalline Belledonne-Ecrins Mountains (France), at a relative fine scale. Using ecological variables and vegetation monitoring plots, we computed 8 species distribution models (SDMs) to predict the potential distribution of 6 alpine species assemblages.

These vegetation communities were first constructed using graph theory approaches based on species' lists elaborated by the Alpine National Botanical Conservatory (CBNA) from field work on monitoring plots. The goal is to elaborate species assemblages (or modules) that are not constrained by phyto-sociological principles but based on the species co-occurrence at the monitoring plots. Species inside a module are thus linked with each other by their ecological affinities and not by botanical characteristics, sustaining the use of ecological dataset to predict their potential distribution. From expert knowledge, the 6 assemblages were selected for their wide representation on the field, their ecological dissimilarities (contrasted niches) and their botanical consistency. They are essentially distributed in sub-alpine and alpine vegetation levels.

Based on the ecological niche theory, species distribution models (SDMs) were used to identify areas that are ecologically suitable for the presence of these 6 assemblages. In all, we used 7 environmental variables, mainly derived from a 25m Digital Elevation Model. Hence, alpine species are greatly influenced by the presence and duration of snow cover and consequently by topography and solar radiation. Moreover, the coarse resolution of climatic data did not match the prerogative of the potential distributions' maps.

The BIOMOD platform was used to compute 8 SDMs (ANN, CTA, FDA, GAM, GBM, GLM, RF, and Maxent). Mean models and coefficient of variations were then calculated based on the best model performances (evaluated based upon expert knowledge). This approach, called "ensemble modelling", gives more consistent results and allows a spatial analysis of the level of agreement between models.

The use of ensemble modelling, using simple ecological datasets, has shown great potential to provide reliable species ecological niches, having important implications in vegetation mapping and thus on management decisions regarding biodiversity conservation. Actually, the predictions show good correlations with field data, few false overlaps between modules and good correlations between transition communities and modules overlaps, revealing the power of these techniques for vegetation mapping in relative complex and inaccessible areas.

Keywords: *Alpine vegetation, graph theory, species assemblages, Species Distribution Modelling, vegetation maps*

The use of models to explore IPM strategies and design pest suppressive landscapes for sustainable agricultural practice

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Abstract: In order for agriculture to move from an unsustainable reliance on broad-spectrum chemical pesticides to a more sustainable future, we need make a transition to a 'total system' approach. Agricultural pest problems need to be considered beyond the crop boundary, and we need to understand the role of the landscape matrix for the suppression of pests in crops as well as providing other ecosystem services, such as pollination.

We combine field-based survey data with a spatially-explicit simulation model to assess the benefits of integrated pest management strategies at the landscape scale. We explore the features of pest suppressive landscapes for a native insect pest in Australia, the Rutherglen Bug (*Nysius vinitor*). The model is designed to explore spatially the effects of environmental drivers including temperature, habitat type and habitat quality, on the population dynamics and dispersal of the bug. This drives its landscape pest status for a given season and location.

We present scenarios evaluating pest control benefits that are likely to be achieved from managing native remnants by weed removal at multiple spatial scales. Our results indicate that the spatial location of weedy pasture in relation to the crop appears to be highly important in determining the density of *N. vinitor* within the crop (outweighing the effect of the overall proportion of weedy non-crop habitat in the landscape), and this warrants further exploration.

Our approach as illustrated in this paper, using models combined with field data to explore Integrated Pest Management (IPM) strategies and design pest suppressive landscapes, will allow farmers to optimize multiple ecosystem service benefits by i) understanding both the hazards and benefits of non-crop vegetation in the landscape ii) providing a tool to help plan the extent and location of re-vegetation plantings. This work has potential to influence agricultural land use policy in Australia, with further work planned to model the implications of landscape change and non-crop habitat management strategies for multiple ecosystem services.

Keywords: *Integrated Pest Management, Landscape Ecology, Sustainable agriculture, Cohort-based, Spatially-explicit, Ecosystem services, Dispersal*

Linking Bayesian and Agent-Based Models to Simulate Complex Social-Ecological Systems in the Sonoran Desert

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Abstract: Interdependencies of ecologic, hydrologic, and social systems challenge traditional approaches to natural resource management in semi-arid regions. As a complex social-ecological system, water demands in the Sonoran Desert from agricultural and urban users often conflicts with water needs for its ecologically-significant riparian corridors. To explore this system, we developed an agent-based model to simulate complex feedbacks between human decisions and environmental conditions. The model was developed in the Upper San Pedro River basin, located in Southeastern Arizona, USA, spatially-defined by the hydrologic model (Figure 1). Cognitive mapping in conjunction with stakeholder participation produced a Bayesian model of conditional probabilities of local human decision-making processes resulting to changes in water demand for each agent type: rancher, urban, and institution. For example, cognitive mapping of ranchers found water availability and profit margins were the two most important factors in decision-making (Figure 2). Probabilities created in the Bayesian model were incorporated into the agent-based model, so that each agent had a unique probability to make a positive decision based on its perceived environment at each point in time and space. By using a Bayesian approach, uncertainty in the human decision-making process could be incorporated. The spatially-explicit agent-based model simulated changes in depth-to-groundwater by well pumping based on an agent's water demand. Depth-to-groundwater was then used as an indicator of unique vegetation guilds within the riparian corridor. Each vegetation guild provides varying levels of ecosystem services, the changes of which, along with changes in depth-to-groundwater, feedback to influence agent behavior. Important ecosystem services in decision-making were identified by local stakeholders in a series of workshops. Using this modeling approach allowed us to examine resilience of semi-arid riparian corridors and agent behavior under various scenarios. The insight provided by the model contributes to understanding how specific interventions may alter the complex social-ecological system in the future.

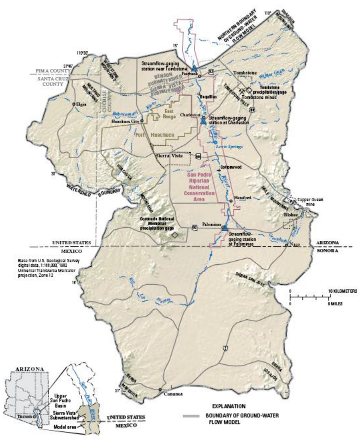

Figure 1: Map of the Upper San Pedro Basin showing extent of the USGS' Groundwater Flow Model (From Fig. 1 in Pool and Dickinson 2007).

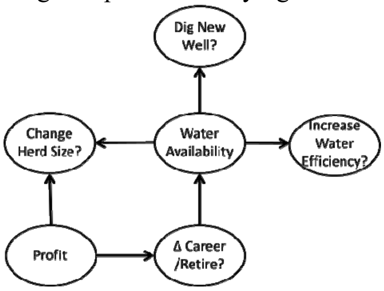

Figure 2: Rancher cognitive map of water-based decisions and contributing factors.

Keywords: *Social-ecological System (SES), agent-based modeling, groundwater modeling, bayesian cognitive mapping, ecosystem services*

Optimising flow management for ecological response and consumptive use

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Abstract: The regulation of flow in river systems and use of water for consumptive and economic purposes has led to detrimental effects on riverine, wetland and floodplain environments in river systems worldwide. In recent years, there has been a concerted effort to develop policies to return water to the environment to minimise these effects. However, there are far fewer instances of actual flows being delivered. One barrier to the delivery of environmental flows is the need to balance environmental and consumptive outcomes, optimising returns for both with a limited volume of water. Various methods are available to help define the flows required to protect specific ecological assets or to mimic aspects of natural flow regimes, but few consider consumptive uses as part of the same set of calculations.

In this paper, we present a method of evaluating flow options using ecological response models incorporated into daily hydrology and irrigation river management models. A multi-objective optimisation approach produces the Pareto frontier of non-dominated solutions, which provides decision makers with a range of alternative optimal management options.

An integrated water resource model of the Goulburn River, Victoria, Australia, is developed that represents the rivers, water storages, operational constraints, water management and consumptive demands on a daily time-scale linked to climate. Models of ecological responses to flow are incorporated into the river model to simulate ecological response and generate environmental flow demands. Storage volumes are used to determine water allocations which in turn determine the area irrigated and relative value of the crop mix. We develop this eco-hydrology model and optimisation approach as a 'proof of concept' example, where the objective functions are to minimise terrestrial vegetation encroachment into the main river channel through the use of environmental flows, while maximising the net relative value of irrigation.

The model is run over 35 years and the results indicate that a range of optimal solutions exist. In the best case for irrigation there is a net relative value (over the 35 years) of almost $17B while terrestrial vegetation encroachment could average approximately 13%. In contrast, it would be possible to reduce the terrestrial vegetation encroachment to just 2%, however, this would reduce net relative value of irrigation to around $12B. Interestingly the latter option would also result in some short-term periods of very high vegetation encroachment. This was because of much lower overall storage volumes resulting in 0% water allocations in some years. Our results highlight the importance of hydrological modelling of both consumptive use and ecological response to understand the feedback mechanism of some management decisions. Between the two extremes are a range of results that provide a clear understanding of what outcomes could be expected for both of the objective functions for all optimised solutions.

The results presented in this paper are applied to a simple representation of the Goulburn River with limited model testing to illustrate the concept and value of integrating ecological response models into hydrological river management models, and how multi-objective optimisation tools can be applied to water management issues. The hydrological feedback loops that occur when environmental flows and consumptive water are ordered and delivered can be complex. Therefore the eco-hydrology and allocation systems must be modelled concurrently to understand the implications and trade-offs involved in managing water allocations.

Keywords: *Ecology, modelling, hydrology, optimisation, environmental flows*

EXTENDED ABSTRACT ONLY

Simple models in planning for a multifunctional landscape under changing market and climate conditions

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Abstract: It is increasingly important to consider a vast range of complex issues when planning around landscape and regional natural resource management issues. The complex relationships between competing interests such as food production, water supply, soil and land degradation, as well as biodiversity can be very difficult to balance, particularly with uncertainty about markets and the impact of climate change. Furthermore, short term planning and management horizons relative to long term agro-environmental processes make it difficult to project the influence of policy options into the future. There is a need to identify and explore uncertainty in the information that informs policy and in turn make management decisions more robust to this uncertainty.

Here we present a series of simple models that enable planners and managers to explore spatially explicit landscape futures for natural resource management. These models are explicitly focused on regional planning and applied within four issue based modules which are designed to enable exploration of potential future states for a range of key drivers that will impact upon future planning. These modules are: the *agricultural management* module provides a systems modeling approach to explore food and fibre production under changing climate and market conditions. The *carbon sequestration* module uses a landscape planning approach within a multi criteria analysis (MCA) to compare the productivity and economic returns from agricultural with that of forestry for carbon abatement under different climate and market scenarios. The MCA creates inclusion (*go*) and exclusion (*no go*) zones for agricultural production and carbon forestry based on user defined thresholds over a set of criteria. The *biodiversity conservation* module uses a cost-benefit approach to inform policy options such as targeted incentive schemes where payments are made to encourage the conversion of agricultural land to conservation. These approaches are aimed at finding the conservation areas that provide the most cost effective investment. The *weed risk* module uses a risk analysis framework to identify areas for targeted weed management under different climate scenarios. Risk layers are developed by combining spatial layers of the likelihood of weed invasion with the potential consequence to agriculture or biodiversity. The risk layers can be used to identify hotspots where there is a high likelihood of occurrence for selected weed species and the economic or ecological consequence of this occurrence would be high.

These four planning modules have been developed into a web-based interface called the landscape futures analysis tool (LFAT). The aim of the LFAT is to provide an accessible and user friendly portal that exposes planners and managers to the science of landscape futures. Through this portal they can explore the different drivers and sensitivities landscape and natural resource decisions. To do this the LFAT enables users to select combinations of variables, targets and land use options as they explore each of the different modules though output maps and summary statistics.

Keywords: *Landscape modelling, futures analysis, integration, planning, simple models*

Modelling the Socio-Ecological System Dynamics of Rubber Agroforests to Design Reward Mechanisms for Agro-biodiversity Conservation

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Abstract: An agent-based modelling approach (LB-LUDAS model) was applied to simulate and visualize the temporal and spatial scale effects of the Payments for Ecosystem Services (PES) scheme on the trade-offs between goods and services in the rubber agroforest landscapes in Jambi Province, (Sumatra) Indonesia. The PES scheme under investigation is a form of eco-certification of biodiversity-friendly rubber agroforests, as an economic incentive to keep rubber agroforests from conversion into monoculture plantations. Within the model, we integrated the concept of PES conditionality, where biodiversity performance measures were set for household agents to qualify for incentives. On the other hand, species richness, carbon sequestration, and natural succession sub-models are imbedded in the landscape agents. During the simulation, we looked at three different price scenarios to determine how they will affect the land-use decision of the agents and the ecosystem services supply. The main results showed that PES for rubber agroforests could offer synergies among carbon emission reduction, biodiversity and livelihoods when compared to the existing land-use practices. At the same time, the scheme could reduce the trade-offs resulting from possible land-use/cover change. The results of the simulation were validated using a role-playing game testing responses to external agents.

Keywords: *Agent-based model, biodiversity performance indicator, conditionality, eco-certification, ecosystem service trade-offs, land-use/cover change, price effect*

Using an integrated river basin model and an optimization algorithm for quantifying ecosystem services and trade-offs in large river basins – Challenges and potential solutions

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Abstract: Land use changes such as increasing bioenergy production come at a cost –trade-offs between food production, water quality and quantity issues, biodiversity and ecosystem services (ES) are known but a quantification of these trade-offs is missing. Another challenge is the spatial variation of the provisioning of ES and their appropriate mapping. Besides production services, we explore the potential of mapping water quality-related ESs for the example of water provisioning and terrestrial water purification. The study points out challenges and potential solutions with regard to quantifying ESs and trade-offs by using the integrated river basin model SWAT linked to an optimization algorithm (NSGA-2) in the neighboring basins of the Saale (ca. 23,000 km²) and Mulde (ca. 7,000 km²) river in Germany. We aim at identifying optimal land use configurations and analyzing trade-offs between different goal functions (low flow, water quality, food and bioenergy crop production, etc.). Several challenges have to be faced: Considering process complexity and scale-related needs to generalize input parameter as well as the incorporation of suitable long-term monitoring data for process understanding, model calibration and evaluation are crucial. Numerous reservoirs in the basins act as interference in the hydrological cycle. Hence, before carrying out the optimization, there is a need to i) analyze historical time series to detect possible interference and trends of climate data, streamflow, and water quality, ii) get information about point (waste water treatment plants (WWTP), industrial discharge points (IDP)) and non-point-sources (fertilizer input), and iii) develop model calibration and spatial optimization strategies. With regard to i), partly contrary trends of streamflow were detected in the Northwestern and Southeastern mountains of the study area with a more distinct decrease of mean discharge in the Northwest – while trends for water quality show mostly improvement over the last decade. Relating to ii), starting with the point sources, methods are discussed that analyze population equivalent, annual amount of waste water and nitrate loading from 350 WWTP and 198 IDP in the Mulde basin to derive a regression equation that will be applied to the larger Saale basin. For the model input regarding the non-point sources, fertilizer inputs based on regional differentiated fertilization recommendations to farmers as well as yield statistics have to be used (statistics of fertilizer consulting programs of the state authorities). Since we work on the impact of different land management options on our objective functions, we have to define agricultural operating-, crop management- and tillage-systems – which is a challenge with regard to data protection laws and the different data management practices in the federal states of Germany. We define these systems by using soil-climate-regions as reference units, and combine agricultural statistics from the communities, the fertilizer advisory systems, farmer interviews and the available information on existing crop rotations. With regard to iii), multi-site calibration strategies will be discussed that consider best the different landscape characteristics of the area. Although first successful simulations were carried out in a smaller experimental watershed of around 320 km², open questions will be discussed about the design of multi-optimization strategies for larger river basins with spatially varying problems and goal functions.

Keywords: *River basin management, Ecosystem Services, trade-offs, water quality, bioenergy, land use, genetic algorithm, crop rotation schemes*

Anticipating social-ecological regime shifts in the Baltic Sea

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Abstract: Many different systems in nature and in society are susceptible to sudden change. Among the best studied of these changes, often called regime shifts, have been marine systems. For example, in the 1980s and early 1990s the fisheries of the Baltic Sea underwent a drastic change, which has still not reversed, from being dominated by cod to being dominated by herring and sprat. Although modelling has been used to understand these regime shifts, traditional modelling approaches suffer from two limitations. First, models tend to focus on ecological dynamics and neglect to acknowledge changes in human behaviour, such as changing harvesting practices or changing management policies, which can develop in response to changing ecological conditions. Second, developing quantitative models of coupled ecological and human behavioural dynamics can be challenging, particularly when the system is moving into previously unknown regimes. Here, we describe a work in progress where we aim to overcome these challenges by producing a generalised model of the Baltic Sea social-ecological system.

By taking a social-ecological approach we consider the linkages and feedbacks arising from social processes, ecological processes and, importantly, those processes that link social and ecological aspects of the system. Considering the social-ecological system has allowed us to identify that in addition to ecological and economic (market) processes that serve to regulate cod stock and fisher income, there are a number of potential social and social-ecological feedbacks that could have contributed to destabilising the Baltic cod fishery at the time of the cod collapse. These destabilising feedbacks include increased specialisation of fishers, overestimation of cod stocks by fishers, excessive government subsidies driven by fisher lobbying, and resistance of fishers to stop fishing cod due to the costs they have sunk into expansion of their fleet.

The dynamical systems approach of generalised modelling will allow us to assess the relative contributions of these different processes and feedbacks to the collapse of the Baltic cod fishery, even in the presence of uncertainties about the details of how these processes work. In order to proceed with the generalised modelling analysis, we need to validate the interactions and processes included in our model, which are so far based on the statements of expert researchers. Data on cod price, cod stocks, and fisherman behaviour will also help to quantify the relative contributions of processes and feedbacks in the model. Using the generalised model, we can then explore the effects of human behaviour and management on the cod collapse and whether alternative management structures may have impeded the regime shift. We could also investigate what may encourage future transitions out of the Baltic's current cod-depleted state. Ultimately, we hope to contribute to a more integrated management of the Baltic Sea by identifying critical social and social-ecological feedbacks that need to be addressed in order to guide the future development of the Baltic both towards more desirable states and away from less desirable ones.

Keywords: *Baltic Sea, social-ecological system, regime shifts, generalised modelling*

EXTENDED ABSTRACT ONLY

Evaluating the potential implications of monitoring and assessment strategies for the management of reef fish populations on the Great Barrier Reef, Australia

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Abstract: The Queensland Coral Reef Fin Fish Fishery (CRFFF) is a $40 million AUD fishery that exports the main commercial species, common coral trout (*Plectropomus leopardis*), to the live fish markets of Asia. The current allowable harvest for the species, 1214 t, is based on historical commercial catches taken by the fishery, and has changed little since 2004. The reliance on historical data to determine the TAC has led to questions regarding the potential profitability and sustainability of the fishery. We have developed a spatially-structured simulation model of the population dynamics and line fishing harvest on the Great Barrier Reef, in order to evaluate strategies used to manage the coral trout population. In particular, we have embedded spatial and temporal monitoring of the simulated population, which feeds into an embedded assessment model that estimates the state of the underlying simulated population. In this paper, we use this tool, the Effects of Line Fishing Simulator (ELFSim), to evaluate the ability of monitoring and assessment models to measure the state of the spatially complex meta-population model that represents the coral trout resource.

Different monitoring strategies included simulating the Long-term Monitoring Program (LTMP) that operated on the GBR from 2005-2009 which sampled length and age data of coral trout from reefs visited by one chartered vessel (randomly selected vessels from the simulated fleet) over the course of a single month. Other monitoring strategies explored included less costly “on board” sampling, which sampled the coral trout catch spatially from the commercial fleet, and port sampling at two different levels of spatial aggregation.

Assessment of the simulated coral trout stock was attempted by embedding an age structured population dynamics model into ELFSim with, and fit to data obtained from the simulated sampling and monitoring strategies. Thus, we attempted to determine how accurately the age-structured stock assessment model estimated the population from the model spatially complex ELFSim operating model.

Results showed that the assessment model was able to capture the age distribution sampled from the ELFsim operating model, but tended to over-estimate the biomass of coral trout in absolute terms. It was however, more accurate in estimating the depletion level relative to pre-exploitation biomass. Results also showed that the assessment model was unable to capture the inter-annual variability in biomass trajectory of the underlying ELFSim operating model. Results also show the effect of monitoring strategy on the ability of the assessment model to estimate the underlying coral trout biomass in the ELFSim operating model.

The implications of the research will inform stakeholders and management on the potential effectiveness of the assessment model to achieve its goal of determining the status of coral trout, a species with a complex spatial meta-population structure. It will also lead to information on the degree of spatial and temporal sampling intensity needed to achieve this goal, and whether such monitoring programs are cost effective in terms.

Keywords: *Bio-economic modeling, management strategy evaluation, ELFSim*

Baltic grey seals – Balancing between Sustainable Management and Fisheries

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Abstract: The population size of Baltic grey seals (*Halichoerus grypus*) has substantially increased in recent years leading to a conflict between seals and coastal fisheries in the northern Baltic Sea. Seal induced catch loss and damage to fishing gear has increased and unknown numbers of seals face unintended by-catch mortality. We analyze different options for sustainably managing the seal populations in order to alleviate the damage to fishing caused by them.

We build a biologically consistent population dynamics model to estimate the temporal changes in the seal population and to predict the development of the population under alternative management options. As the uncertainty related to the subject is high, modeling will be conducted by using probabilistic approach and Bayesian methods. This allows the assessment of the past changes in seal population size and demography, and forecasting how alternative management decisions affect the population by explicitly describing the uncertainties at the same time. Our model is age structured and it describes all the basic demographic processes in seal population. Data and prior information from several complementary sources will be used to infer the parameters of the model. These include, for example, survey counts, by-catch reports, fishing and hunting statistics, data from sample individuals, expert interviews and literature.

We estimate the risks faced by seals with alternative scenarios for hunting, by-catch and ice conditions in the breeding areas. The seal hunting and fisheries management options are constructed based on interviews of hunting, fishery, seal research and conservation experts. The alternative ice condition scenarios are based on published climate change scenarios.

Keywords: *Ecosystem model, Uncertainty analysis, Gaussian process*

Examination of a tropospheric ozone control methodology from the explicit representation of POCPs across varying temporal and continent spatial domains

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Abstract: Ozone is an internationally recognized criteria air pollutant, and remains a major concern despite more than 25 years of regulation at the national level. A method developed by Derwent and co-workers (1996, 1998) and initially applied in the United Kingdom (UK), was to define POCPs (photochemical ozone creation potentials), as a means of ranking, in a semi-quantitative way, the contributions of different non-methane volatile organic compounds (VOCs) to ozone formation.

To develop an understanding of the differences in high ozone formation in other regions of the world, subsequent modeling studies determined POCPs for the USA and Asia (The Pearl River Delta (PRD), China and Hong Kong (HK)), each region with different VOC and NOx emissions and characteristics. In this study POCP's are calculated on the Australian continent, for the city of Perth, of notably lower levels of air pollution than all previous studies. The POCP values were generally found to be lower than those determined previously in the UK, USA and Asia. An assessment is made of the similarities and differences between the four continents, first by VOC group classification and then by analyzing the ranking of the VOC in terms of the highest 50 POCP values from across all studies.

Despite different geographic locations, meteorology and emissions (VOC and NOx), leading to differing temporal peak ozone duration and concentration at the receptors, a number key VOC were found to he high ozone contributors across all locations. This shows a dominance of alkene and aromatic compounds, and 25 of the 50 VOC with the highest POCP values are common across the region studied. These VOC are ethene, propene, isoprene, the butenes and pentenes, and though some of the aromatic compounds differed between the regions, the trimethyl benzenes were also consistently highly ranked. They are identified as key target VOC for consideration in emissions reduction strategies. Other VOC that influence ozone in specific regions were found to generally rank low in the highest 50 POCP groups, however the region specific ranking of formaldehyde, acetaldehyde and diethyl ether can be inferred as significant from their higher ranking positions in HK, Perth and the USA, should also be taken into consideration in targeted reductions.

Given the commonality of the identified key VOC with the much more highly polluted airsheds also shows that the determination of POCP's for Perth has provided insightful intercomparisons, using the POCP ranking from across the regions, to identify key anthropogenic emitted VOC, that will most likely continue to be significant contributors to high ozone events in Perth, as the region experiences high population and development growth, with a significantly increasing burden on the regions VOC and NOx emissions.

The study provides further support that the POCP methodology has considerable potential for application in policy development. The need for practical abatement policies is substantial with the growing need to redress the large increase in the occurrence of episodic high ozone concentrations in many rapidly developing regions of the world.

Keywords: *Photochemical Ozone Creation Potentials (POCPs), Volatile Organic Compounds (VOC), photochemical model*

Modelled dispersion of emissions from a copper smelter, Karabash, Russian Federation

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Abstract: Copper has been smelted at Karabash, Russian Federation since the 1830s. The by-products of commercial copper smelting include SO_2 and metal-rich particulate matter. Such particulates may cause a risk to human health. The main metals of concern from smelter emissions are usually As, Pb, Cu, Cd, and Cr for which a common conduit for entry into the food chain is via the irrigation of crops with contaminated water. We assessed an air pollution model aimed at estimating the smelter's emissions using metal accumulations in transplanted lichens. Lichens are widespread geographically, and have morphological features which make them reliant on airborne minerals in their metabolism. We aim to gauge the effect that the smelter was having on the locality through predicting dry deposition resulting from the smelter emissions as modelled by TAPM. Using an arbitrary emissions rate and we convert modelled deposition into bio-accumulations in the lichen, forecasts which are calibrated using build up in the lichens.

Near-source atmospheric transport and dry deposition of particulate metal emissions around the Karabash smelter, Russian Federation were simulated using an air pollution dispersion model. There were three stages: setting up and running a model of the air pollutant dispersion and dry deposition around the smelter using estimates of the source strength, modelling the metallic accumulations in transplanted lichens around the smelter and thirdly, analysing the results and the agreement between estimated and observed accumulation within the transplanted lichens. The lichens (*Hypogymnia physodes)* were transplanted around the smelter between 10th June and 16th September, 2011, and analysed. The metal accumulation (As, Cu and Pb) were compared against the air pollution deposition modelled from the smelter (TAPM, CSIRO). The simulator TAPM (*Eulerian*, *Lagrangian* or mixed) and a continuous point source representing the smelter were used together with meteorological data. TAPM also takes into account surface topology of a locality, including orography and vegetation cover. Model runs were undertaken for a single species tracer and obtaining dust deposition using particle tracking assuming particle sizes PM2.5 and PM10 and using the quantum APM (PM <10 microns).

Lichen samples ranged in concentrations: 4-105 ug/g (As), 24-909 ug/g (Cu) and 89-841 ug/g (Pb). An analysis of wind conditions revealed that the wind blew from a direction between West and North-North-East for 80% of the time during the modelling period. The pollution modelled as having accumulated across the sites ranged from 0.14-4.2 ug/m^3 with the modelled dry deposition accumulating to between 85-838 ug/m^2 (PM2.5); 641-7202 ug/m^2 (PM10); and 10328-31901 ug/ m^2 (APM). A linear relationship was found between the air pollution modelled and metal concentrations found in the lichen samples for.

The air pollution model has the potential to provide an accurate way to estimate pollution load on an area surrounding a smelter. This can then be used to fore- or hindcast potential loads on the surrounding environment. Historically, Pb levels in soil sampled around the smelter were between 1.5 and 2 mg/kg. As these soils dry, their re-suspension may elevate levels of lead which will attach itself to lichen in close proximity to the smelter. Around 650,000 tonnes of ore are processed at Karabash each year with typical fugitive emissions likely to amount to 2.2 kg per tonne of PM_{10}, which equates to 45.3 g/s or less than a third of the emission rate assumed at the point source in the model, 145.4 g/s. Assuming the fugitive emission rate is applicable to Karabash, the large majority of the lead adsorbed by lichens around the Karabash smelter is likely to be caused by the re-suspension of contaminated soils.

Keywords: *air pollution modelling, mining, lichen*

Weather, Climate, and the Environment Data Linkage with Human Health and Wellbeing Data Sets: MED-MI

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Abstract: A large part of the global disease burden can be linked to environmental factors, underpinned by unhealthy behaviours. Research into these linkages suffers from the lack of common tools and databases for carrying out investigations across many different scientific disciplines. The MED-MI Partnership brings together leading organisations and researchers in climate, weather, environment, and human health and wellbeing. Tis will enable data stored by different organisation in different locations in differing formats to be linked and hence utilised.

The aim is to create a central data and analysis source as an internet-based platform which will be a vital common resource for medical and public health research in the UK and beyond. We will link and analyse complex meteorological, environmental, and epidemiological data. This will necessitate linking by spatial and temporal parameters to ensure inclusion of appropriate data and will be housed on an expanded database management system at the University of Exeter. This is a vital step to translate this data and analysis resource into epidemiologic, clinical, and commercial collaborative applications, and thus, improved human health and wellbeing in a rapidly changing environment. The object is to perform a data "mashup" by linking data sets with appropriate quality controls and confidentiality.

Translational applications will:

- facilitate novel research into environmental exposures and health using integrated models;
- rapidly identify "hot spots" for targeted interventions;
- provide healthcare practitioners, public health planners, and environmental managers with relevant information for improving services for locations and populations at risk;
- initiate and evaluate interventions to reduce the exposures, and thereby the health effects at both the individual and population levels;
- disseminate and provide access to data as part of outreach and engagement with the research community, policy makers and civil society.

Extant data stored in various organisations will be combined enabling climate, weather and environment data to be linked and analysed with human health and wellbeing data. Three exemplar projects have been proposed including examination of the associations between extreme temperatures, air quality and mortality, B) climate, weather and infectious disease, C) climate, coastal and ocean dynamics and harmful algal blooms. It is predicted that these projects will see data derived from the Met Office UK linked with a variety of extant human health cohorts or data sets such as CRPD, UK Biobank, ONS mortality data and 1958 Birth Cohort. With appropriate confidentiality and ethical safeguards, the Platform will be available to UK and other researchers. It is envisioned that access to linkage will be via either local or remote access, there will be differing layers of user access and the portal will contain a library of tools including visualisation, mapping, commentary and notation.

Keywords: *Data linkage, environment, health, meteorology*

Application of a protectability index to assess habitat eutrophication in designated areas

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Abstract: Under the UNECE LRTAP Convention protection of ecosystems is routinely evaluated in integrated assessment by calculating exceedance of critical loads, defined as the maximum levels of deposition sustainable without adverse effects. Such assessments using the UK Integrated Assessment Model are able to quantify the extent of exceedance regionally for different broad habitat categories. Although this provides an aggregated view useful for policy development, it cannot quantify impacts upon individual sites of special scientific interest (SSSI) or other sites designated under the Habitats Directive or the Birds Directive of the European Union.

Compilation of critical load data for designated sites by JNCC has enabled a more detailed consideration of those ecosystem areas of concern, leading to the development of a "protectability index" which indicates different degrees of risk for different habitats within designated sites, ranging from "protected with a high level of confidence" to "un-protectable" where exceedance is so large that reducing deposition to eliminate it is not feasible.

As designated sites are often nearby, or adjacent to agricultural livestock, they can be unduly affected by short-range dry deposition of ammonia emissions. We evaluate current (2010) and projected (2020) impacts upon a range of habitats in designated sites which display very low to very high sensitivities to nitrogen deposition. With agricultural emissions of ammonia consistently difficult to reduce, we compare these impacts with an hypothetical scenario in which dry deposition of ammonia – which is dominated by local sources – has been reduced, indicating where local control measures may be useful. We conclude that local mitigation measures may present an effective means for reducing eutrophication in designated sites.

Keywords: *Critical Load Exceedance, Eutrophication, Designated Sites (SSSI), Protectability Index*

Bridging the gap between air pollution models and epidemiological studies

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Abstract: Air pollution models developed for policy support have traditionally generated aggregated population exposure metrics – such as population weighted mean concentrations, years-of-life-lost or disability-adjusted-life-years – as a proxy for impacts upon human health. With the latter also using results from epidemiological studies, these metrics are useful for gauging whether policies potentially reduce health impacts, but they do not account for the movement of individuals, and air pollution models could provide more focussed information for evaluating real-world health impacts. However, annualised air pollution models can describe the spatial variation of different pollutants for use in health impact assessments based upon daily activity patterns of individuals.

Focussing on airborne particulate matter (PM), we acknowledge that there is no consensus on the relative toxicity of different components of PM, with reviews by the WHO investigating various causative mechanisms, implying specific components as particularly toxic, such as diesel particulates which are also identified as a carcinogen. Recognising that epidemiological studies already utilise outputs from air pollution models, we highlight the complexity of airborne PM in relation to size fractions, species composition, source attribution, control of emissions, and health impacts, and show how air pollution models can provide more focussed information to benefit epidemiological assessments.

Drawing on work attributing health effects to individual PM constituents, and source apportionment by the UK Integrated Assessment Model, we are able to distinguish the spatial distribution of concentrations of components which may have differing impacts upon human health. Understanding these spatial variations and their coincidence with vulnerable populations (eg. schools or hospitals) represents a step towards air pollution models providing outputs of greater utility for epidemiological studies.

With the emphasis upon reducing health impacts under the Directive on ambient air quality and cleaner air for Europe, the provision of more focussed metrics within air pollution models should enable policy makers to direct abatement strategies towards the industrial and residential sectors with the greatest combined impact on human health, simultaneously providing better data for epidemiological studies evaluating the impacts upon mobile populations.

Keywords: *$PM_{2.5}$, Health Impacts, Population Exposure, Integrated Assessment*

Developing a virtual observatory for personal exposure assessment

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Abstract: The development of new sensor technologies and the diffusion of smartphones and other mobile devices into everyday life gradually make it easier to track the location and activities of individuals, as well as measuring ambient air pollutant concentrations, in space and time. Both aspects are prerequisites for a detailed assessment of personal exposure to air pollution. In order to upscale from the personal exposure of individuals to population groups, however, monitoring studies require a representative sample of the population of a city or region. And while a variety of field studies and citizen science projects demonstrate the feasibility of such approaches, deploying a large number of mobile sensors for an extended period of time is both costly with regard to the time and effort spent by study participants, and may generate substantial amounts of data which are not easy to manage and evaluate.

In this paper, we demonstrate how the use of fine scale (1 x 1 km grid at 1 hourly resolution) atmospheric chemistry transport model results in a dynamic GIS environment can be employed to simulate the movement of virtual study participants across an urban area. We describe the approach to model the accumulation of personal exposure of virtual individuals in the Edinburgh city area as they commute, spend time at home and work, and engage in leisure activities, taking into account the transfer of pollutant concentrations from modelled outdoor levels into indoor or vehicle environments by modifying transfer functions. Time spent indoors and in other micro-environments will be modelled based on field studies conducted in winter and spring in the same area as described by *Steinle et al.,* this session.

The outcomes of this work will be used to determine cost-effective strategies for sampling individuals for real-world personal exposure studies. Ultimately, the aim is to develop a GIS-based decision support tool for the simulation of individuals or groups being exposed to varying levels of modelled air pollution, allowing the assessment of both current and future air pollution regimes.

The specific method applied to support the characterization of the spatial variability of air pollutants in an urban context is based, in a first step, on the use of machine learning techniques to process aerial photographs of an urban area in ARC GIS to split the study area into compartments with homogeneous micro-climates and micro-environmental conditions. The results of this characterisation are then evaluated against air quality information from official fixed-site monitoring stations of Edinburgh. The authors identify three main factors that can influence the micro-environmental conditions regarding air pollutant concentrations: land-use, urban orography (e.g. street canyons) and road type classification, respectively the proximity to main roads.

Land-use has been extracted from aerial photography splitting the image into homogeneous areas (segments) and combining three different machine learning techniques to classify the segments in the four selected categories. The urban canyons are assessed computing the sky view factor and the aspect ratio of the building as suggest in recent literature. The roads are classified in five different classes to take into account the different level of expected traffic emissions for each class. These three main factors are compared with monitoring data from monitoring stations to verify which factors drive the spatial variability of the air pollutants. The presented research is still a work in progress and preliminary results are shown here. An accuracy of 96% was achieved for segment classification using a subset of 100 segments to train over 160 verified segments. In the next step, the modelled atmospheric concentrations of key pollutants (particulate matter, nitrogen dioxide) is distributed within the 1 km grid cell using the thus characterised compartments in order to provide a virtual high resolution (~ 10 m) environment in which the personal exposure of individuals can be assessed.

Keywords: *air pollution modelling, machine learning, GIS*

Personal exposure to $PM_{2.5}$ – results from a pilot study

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Abstract: Ambient urban air pollutant concentrations are subject to high spatial and temporal variability. Equally, today's urban population shows varying individual behavioral and time-activity patterns whilst moving through an ever changing environment. Fixed-site monitoring approaches cannot capture the spatiotemporal complexity of personal exposure to air pollution. Personal exposure monitoring methods have evolved and present a viable option to get a more accurate picture of daily individual exposure. By providing a more detailed evaluation of different exposure routes and contributions, its outcomes can support policy and public health decisions and serve as input for exposure models.

The work we present is based on the application of a low-cost, portable solution to measure geo-referenced, ambient concentrations of fine particulate matter ($PM_{2.5}$). Data has been collected with the help of a non-representative group of volunteers at the UK Centre for Ecology & Hydrology. In a first phase of data collection (autumn 2012, 19 individual profiles) volunteers were advised to follow their usual patterns and provide feedback about feasibility, practicality and issues with data collection. Data collected includes weekdays as well as weekend days and in one case several days of holiday travel. In the second round of data collection (spring 2013, 16 individual profiles) the focus was on collecting full 24 hour profiles. These profiles are generally shorter i.e. often only 24 hours rather than several days as in autumn, and include less weekend days.

Based on the data collected, six microenvironments (MEs) have been defined and allocated. GPS tags and time-activity data have been matched with particle number counts with a frequency of one per minute to eventually determine exposure in the identified MEs. Key challenges in data processing arise due to the need for time-stamp matching as the data is logged at different temporal resolutions by the different sensors. Contextual data currently has to be added manually, based on time-activity diaries and follow-up interviews.

Each data point has been assigned to one of the following classes – indoor, outdoor urban or outdoor rural - with the aim to apply specific functions to derive indicative particle mass concentrations for $PM_{2.5}$ from particle counts for the respective categories. Formulas for urban and rural will be derived based on comparative measurements with reference instruments at fixed monitoring stations (one urban, one rural), over several days. For indoor environments we applied a formula derived from smoke chamber experiments based on second-hand smoke exposure.

Results confirm that a large amount of time is spent in indoor environments (90%), a fact which is often neglected in traditional assessment approaches based on national fixed-site monitoring stations. The split between outdoor rural (4%) and outdoor urban (6%) is strongly influenced by the rural location of the work place for all but one of the volunteers and weekend activities taking place in rural Scotland. This will likely be very different for a more urban dominated group of people. Short-term peak exposures occurred in the home and private residential building environments while cooking.

Most frequently volunteers in this study use private cars, followed by buses and walking. Train and ferry are only used for longer distances (work or holiday travel). With 6% only, the bicycle is only marginally used as transport mode in this study.

Keywords: *Personal exposure, $PM_{2.5}$, Microenvironments, time-activity, GPS*

Can a regional chemistry transport model simulate high polluted areas for human health and policy studies?

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Abstract: Regional transport models with horizontal resolution of a few kilometers (<5km) have already been applied to assess the impact of air pollution and climate change on human health. An atmospheric chemistry transport model (ACTM) is used here to investigate the changes of model calculated pollutant concentrations such as particulate matter (PM) and ground-level ozone, both spatially and temporally, when the ACTM is applied with different horizontal resolutions as shown in Figure 1 (50, 5 and 1 km). The model domain is relatively large covering mainland Scotland (UK) with inclusion of both highly polluted areas (e.g. the densely populated) and clean areas (e.g. the rural Highlands) in the simulation. The ACTM used is based on the EMEP model but adapted to the UK and Scotland. With each increase in model resolution the chemistry regime changes substantially, especially in polluted areas even before any simulated chemistry takes place. The emissions are injected and homogeneously mixed in the relevant grid box, which means that as the resolution changes the box volume changes as well and subsequently, the pollutant concentration as an initial condition. An example is ozone and its highly non-linear relationship with NO_x concentrations. Here, we explore how changing resolution may switch the model domain from being NO_x limited to VOC limitation, which has profound implication for the local control measures that would be effective in reducing ozone concentrations. These implications are explored and compared with available hourly observation data.

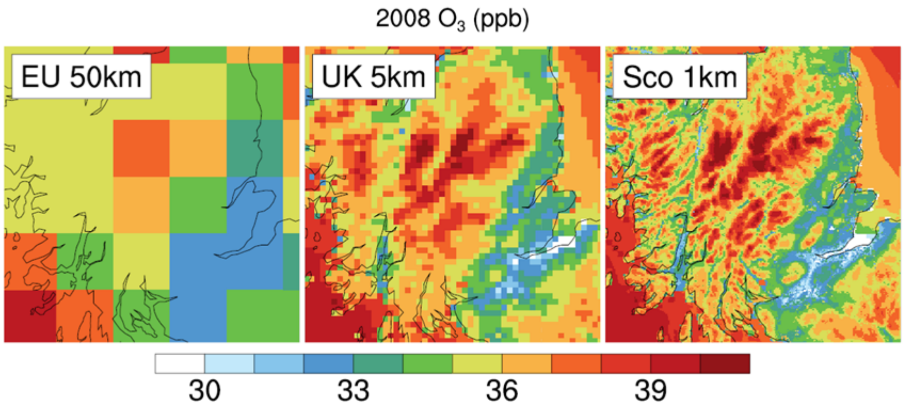

Figure 1: Annual average surface ozone for the year 2008 calculated by the EMEP4UK model at 50, 5 and 1 km horizontal resolution for the Scottish model domain (UK).

Keywords: *air pollution modelling, atmospheric chemistry*

Impact of Chemicals and Ionizing Radiation on Human Health: Need for Adapted Modeling Techniques

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Abstract: Epidemiological effects of environmental pollution can be modelled in many different ways. In literature the term "integrated environmental health impact assessment" is used, which is defined as a means of assessing health-related problems deriving from the environment and health-related impacts of policies and other interventions that affect the environment, in ways that take account of the complexities, interdependencies and uncertainties of the real world. The concept of "exposomes" which is a widely accepted approach for the relationship between environment and disease risk supports a holistic point of view.

The first step is to determine the indicators in order to define a multi-indicator system. In our approaches we take breast milk samples polluted with pesticides and the human sex ratio at birth disturbed by ionizing radiation as examples. For decades mankind knows that dangerous chemicals are found in human breast milk. Research has shown how chemicals in our environment can profoundly affect development, growth, maturation, and reproduction by mimicking hormones or interacting with hormone receptors. The effect of environmental contaminants on health is a major concern because exposure is associated with a number of diseases, including cancer, diabetes, and infertility. Ionizing radiation is known to have a negative effect on human health even at low doses. Concerning ionizing radiation, risks have been known almost as long as ionizing radiation itself that means since 1896. Various forms of cancer, birth defects (malformations, Down syndrome, etc.), infant mortality, heart diseases, etc. occur.

In our presentation we will give two examples, one on the modelling of pesticides in breast milk samples in Turkey, Finland and Denmark and the second one on the statistical assessment of ionizing radiation near a nuclear storage site TBL Gorleben (Transportbehälterlager: nuclear waste shipping casks storage) in Lower Saxony, Germany.

Concerning the data evaluation of chemicals, we apply an appropriate ordinal data analysis method to find out conformities and differences in data sets. This is a discrete mathematical method named Hasse diagram technique. The software package used is the PyHasse software. This software is written in the programming language Python by the third author and is under constant development. PyHasse comprises several modules which are of great support also in the data evaluation of environmental health data.

With respect to the modelling of the relationship between the perturbations of sex ratio with respect to the occurrence of ionizing radiation we apply appropriate regression techniques. To assess time trends in the occurrence of boys among all live births, and to investigate whether there have been significant changes in the trend functions in a time slot, we apply ordinary linear logistic regression. This involves considering the male proportion among all male (m) and female (f) births: $p_m = m/(m+f)$. Important and useful parameters in this context are the sex odds: $SO = p_m/(1- p_m) = m/f$, and the sex odds ratio (SOR), which is the ratio of two interesting sex odds if those two sex odds have to be compared, e.g. in exposed versus non-exposed populations. We used dummy coding for single points in time and for time periods as well.

With these two adopted confirmative modeling techniques we demonstrate relationships and interdependencies between chemicals / ionizing radiation on one side and human indicators (breast milk / sex ratio) on the other side. The underestimation of the influence of environmental pollution on human health is irresponsible to current and future generation. Not only more research in this area should be initiated and performed but it is an urgent need to act more prudently with handling chemicals and ionizing radiation. Modelling techniques must support these efforts.

Keywords: *pesticides, ionizing radiation, environmental health impact assessment, partial order modeling, linear logistic regression*

Air Quality Forecasting in Europe using Statistical Persistence

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Abstract: We present an application of a single-indicator forecasting model to predict short-term urban air pollution levels in Europe. Prior knowledge of hourly, daily, and weekly levels of pollution can assist urban planners in policy and management procedures. Moreover, predictions using large-scale pollution forecasting systems, such as the Monitoring Atmospheric Composition & Climate program and the obsAIRve project, can be supported at the local scale by a statistical model using historical data from ground stations. An example of the use of historical data from ground stations is provided in the previous work of Chiera *et al.,* [2010] in which forecasts of the El Niño Southern Oscillation, represented by a two-state digital signal of the atmospheric pressure, were provided. Key to these forecasts was the concept of persistence, introduced to capture the observed behaviour of the digital signal remaining in one state for a prolonged time, before switching to the other state. This persistent behaviour was captured using Bayesian statistics to yield the *CFZG Model*, that is an adaptive Bayesian single-indicator forecasting model of a quasi-stochastic climate process.

In this paper we augment the methodology of Chiera *et al.,* [2010] to produce a multi-indicator model to predict pollution levels at measuring stations located in 36 European nations, based on observed persistent behaviour in air quality. An attractive feature of the adapted usage of the CFZG model is that it can be applied to multiple pollutant signals including all of the primary European pollutants such as Nitrous Oxides, Particulate Matter, Volatile Organic Compounds and Ozone. Unlike the single-indicator CFZG model, which used measuring stations from two locations only, we use measuring stations for pollutant signals which are geographically disparate, located in both rural and urban sites across 36 countries, all of which are registered with the European Environmental Agency. We present examples of typical nitrous oxide and ozone levels across selected sites and forecasting results for our chosen case study — rural Bosnia-Herzegovina — and compare the forecast against a control test that uses a random signal.

Keywords: *Air Quality, Statistics, Persistence, Modelling, Forecasting, Bayesian*

Spatio-temporal pattern of rice production in Bangladesh: Interaction of climate and management practices

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Abstract: People of Bangladesh mostly depend on rice for their dietary requirements and it is the main staple food. Rice occupied 77% of agricultural land and about 70% of direct human calorie intake comes from rice in Bangladesh. Rice production is variable in space and time and depends on biophysical conditions, climate and management practices. Because of the importance of rice for Bangladesh it is necessary to assess which factors cause regional differences in production. This is a basis for the development of spatial indicators that show if a region produces rice at full potential or if there are possible improvements that can be achieved through changes in management.

Bangladesh has a long term (30 years) record of rice yield, bio-physical and climatic data. Station base climate data was obtained from the Bangladesh Meteorological Department (BMD). Rice yield, cropping intensity and irrigation data has been collated by the Bangladesh Bureau of Statistics (BBS) from 1981 to 2010 and was extracted from the annual reports. The government reports distinguish three varieties of rice (e.g. *Aus*, *Aman and Boro*) that are grown at different seasons. *Aus* mostly covers pre monsoon (March to August), *Aman* is typically rain fed (June to November) and *Boro* generally irrigated (December to May).

The main aim of this study was to analyze the direct effects of climate and management factors on rice yield. Specific objectives were to evaluate data quality, to assess spatial and temporal changes of climate and management influences as well as yield and to evaluate the relative importance of these factors on yield. We harmonized the data by spatially interpolating climate station data for rainfall and temperature at monthly time intervals and summarized by region. These were then aggregated for the growing seasons of the different rice varieties based on the crop calendar of Bangladesh. Cropping intensity is estimated based on the proportion of the land use times the number of harvests per year. We used linear mixed models to differentiate between climatic and management influences.

The results show an overall increase in rice for three varieties at national level but rates differ substantially amongst regions. Cropping intensity has increased until 1991 but has been relatively steady during the last 20 years of the study period. Area under means of irrigation (e.g. power pump, tube well, canals and others) are variable regionally but ground water irrigation has increased. Linear mixed model were used to assess the influence of variable combinations on rice yield. The management appears to have stronger influence on rice yield than climatic conditions. A large proportion of the variance is related to districts and cannot be explained by the data. Furthermore, there is an increase over time that remains unexplained.

The present study shows that some of the improvements are related to groundwater extraction, which may not be sustainable over time. However, there are spatial differences that indicate that there is further potential for improvement. More investigation on other management issues (e.g. application of fertilizer and pesticides, ploughing methods and tools etc.) will improve our understanding of regional variation of rice yield in Bangladesh. This spatial analysis has contributed to an improved understand the biophysical and management limitations.

Keywords: *Rice production, climatic variable, cropping intensity, means of irrigation, spatial analysis*

Crop phenology based on MODIS satellite imagery as an indicator of plant available water content

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Abstract: Maintaining agricultural productivity into the future is one of the most important goals of our society. The world's vast grain production areas in arid environments have a high sensitivity to climate change, thus demanding accurate future predictions. Management and decision making depends on an understanding of complex spatial and temporal interactions between rainfall, temperature and soils, but detailed soil information is extremely costly and generally unavailable.

Crop phenology, the timing of plant growth and developmental stages, is the combined response to environmental factors such as soil, water and temperature. Crop phenology plays an important role in crop growth models and agronomic management. In Mediterranean environments like South Australia, water is the driving factor for crop growth. In these rain-fed farming systems, water availability largely depends on rainfall amount and seasonality and the capacity of the soil to retain rainfall inputs and hence make water available for crops. Plant Available Water Capacity of soil (PAWC) is an important measure of the spatial and temporal variability of crop growth and yield, but there is a paucity of detailed maps at a management relevant spatial resolution and extent.

In this study, different phenological metrics derived from MODIS NDVI imagery were assessed over sites of known PAWC and cropping history. We used the metrics:

- NDVI at the onset of greenness (Onset) and time of Onset (OnsetT)
- NDVI at peak greenness (MaxV) and time of maximum greenness (MaxT)
- The length of the growing season (WidthGS)
- Rate of greenup (GURate)

The green up rate of the curve (GU-rate) showed the most consistent difference between soils of different PAWC. The Rate of Green up is higher for the soil points with relatively low PAWC. Some of the variability in the difference between sites with low and high PAWC can be explained with rainfall amount and seasonality but the relationship is complex.

The results indicate that the crop phenology derived from MODIS satellite imagery is consistently different and may therefore provide useful information about site conditions, which would allow improvements to the spatial detail in soil maps.

Keywords: *Digital Soil Mapping (DSM), remote sensing, satellite imagery, spatio-temporal*

Drought risk to reforestation: simulation as a recurrent event

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Abstract: The retirement and reforestation of farmland holds great potential for redressing declines in biodiversity and ecosystem services, and the mitigation of climate change through the long-term biosequestration of carbon. However, barriers remain to the adoption of reforestation in agricultural landscapes. Reforestation is costly, with landholders incurring substantial upfront expenses in site preparation and plant establishment. In the absence of irrigation, drought in the first few years after planting can cause seedling mortality and the failure of plantations to establish. Projects may then be abandoned, with the costs of establishment sunk and future revenue streams lost. Alternatively, the plantation may be re-established, thereby incurring significant re-establishment costs. As these costs are incurred early on in the investment period, they have a significant impact on the risk profile and financial viability of reforestation investments through the pressure on capital and labour, and the impact on cash flow. Understanding the likelihood of drought events, and how it varies over space and time, is necessary for informing the financial evaluation of reforestation investments and, in turn, achieving significant carbon sequestration in the land sector.

To understand the impact of drought on carbon sequestration and economic returns to reforestation we need to quantify the frequency and likelihood of these events occurring. Drought is a discrete event in time and space. Time-to-event data can be analysed using a family of statistical techniques often referred to as *survival analysis* in medical science (e.g. life expectancy following diagnosis) or *failure analysis* in engineering (e.g. time to failure of a structure). There are few examples of time-to-event analysis of environmental processes.

In general terms, we can plot a histogram of the time-to-event for a phenomenon. The curve fitted to this histogram is the instantaneous failure rate $f(t)$ and the area under the curve = 1. Then, for any given time t, the area under the curve to the left is the proportion of individuals that have experienced the event $F(t)$, with the proportion of survivors $S(t) = 1 - F(t)$ to the right. An important aspect of survival analysis is the instantaneous hazard rate $h(t) = f(t)/S(t)$, which is the likelihood that an individual known not to have experienced the event at time t-1, will experience the event at time t. The instantaneous hazard rate is used in this study to model the likelihood of drought occurring. The beauty of time-to-event analysis is the ability to utilise incomplete or *censored* data. Censoring occurs when the event either has no known start (left censoring) or no known end (right censoring). This is important in analysing drought information using remote sensing data as the length of time for which we have data is often short compared to the median length of time for events to occur. Recurrent event analysis a special type of survival analysis that employs a parametric frailty distribution that enables variation in time-to-event between subjects. The frailty distribution enables us to characterize the spatial heterogeneity in drought events across Australia.

We quantified the likelihood of drought events in Australia, and how it varies over space and time, to inform assessments of the cost-effectiveness of reforestation. We mapped drought events from historical monthly weather data. We also created two climatic covariate layers by taking the first two principal components derived from factor analysis of 35 climate layers created using ANUCLIM. The two covariates were similar to mean annual temperature and rainfall layers. Recurrent event analysis with a shared frailty model was used to quantify the likelihood of drought across Australia as a function of the covariates. We took a random sample of 20,000 grid cells across Australia. We tested a range of different models, distributions (exponential, weibull, gompertz, loglogistic, lognormal) and frailty distributions (gamma, inverse Gaussian, positive stable) and selected the best fit using AIC and BIC. Instantaneous hazard rates were then quantified and mapped for use in stochastic simulation models of forest growth rates, carbon sequestration, and economic returns.

Instantaneous hazard of drought showed spatial patterns over Australia but was not significantly correlated with climatic variables. This information is useful for informing the financial evaluation of reforestation investments and, in turn, achieving significant carbon sequestration in the land sector.

Keywords: *Drought, time-to-event analysis, survival analysis, modeling, spatial, simulation*

EXTENDED ABSTRACT ONLY

Linking Spatial Inundation Indicators and Hydrological Modelling to Improve Assessment of Inundation Extent

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Abstract: Wetlands are extremely valuable, both intrinsically and for the ecosystem services they provide. Increasingly, the health of these systems is threatened by anthropogenic landscape modification and climate change. To conserve and manage wetlands in the face of these threats, it is essential that environmental water requirements (EWRs), including past inundation regimes, are understood so water needs can be supplied in the future. However, determining past inundation regimes is difficult. Very few wetlands have the comprehensive records of inundation that are required to determine EWRs and calibrate models, and the vast majority of wetlands have no record of inundation regime at all. Generally, two approaches are used to reconstruct wetland inundation regimes; remote sensing or hydrological modelling. Remote sensing methods have applied spectral indices of inundation to multi-temporal archival satellite imagery and developed simple empirical models to link inundation extent to rainfall or stream flow records. Hydrological models are another approach to represent inundation extent, using a water balance and simple relationships between volume and area based on the wetland bathymetry. This paper aims to test whether a combined remote sensing - hydrological modelling approach can lead to improved results compared to either method in isolation.

The study was conducted over Lake Hawdon in the South East of South Australia, consisting of a northern basin, with a large drain cut through the middle to alleviate extensive inundation, and a connected southern basin. The remote sensing component mapped inundation extent from multi-temporal Landsat band 5 density slicing over a 20 year period. The remotely sensed inundation extent was validated against recent (2009 – 2011) inundation depth gauges, demonstrating the accuracy of this approach. A simple empirical model to predict total inundation extent from gauged flows was also developed. However, the relationship was found to have limited accuracy, probably hindered by the complex hydrology and hydraulics between Lake Hawdon North and South, and the drain running through the northern basin.

A hydrological model was constructed by calibrating rainfall-runoff models to flow data available in the region, with data commencing in the early 1970s, but with large gaps across a number of sites. In developing the water balance model of the two lakes it was found that a number of combinations of evaporation, seepage and conveyance between the basins and the main drain produced similar results when compared to the downstream flow. As such, using the flow data alone, it could not be determined which combination produced the most accurate representation of water moment and fluxes in the wetlands.

Including the remotely-sensed inundation area provided another source of information to calibrate the hydrological model, allowing the parameters involved in the wetland storages to be more constrained. Therefore, the remote-sensing constrained hydrological model provided greater confidence in the representation of processes occurring in the simulated wetland storage, and hence is more appropriate to be applied on a validation period and for scenario testing. The findings of this research should inform selection of methods for quantifying past wetland inundation regimes, which will in turn define necessary EWRs, and ultimately inform better management of wetlands in the face of increasing water scarcity or demand.

Keywords: *Remote Sensing, Hydrological Modelling, Inundation Modelling, Environmental Water Requirements.*

Using spatio-temporal vegetation imagery for arid lands monitoring

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Abstract: Monitoring change in land condition is critical for environmental management. In particular the remote wilderness regions of the arid zone hold special value because of their biodiversity and their extent and role in carbon cycling. They provide benchmark information about ecosystem structure and function in unmodified landscapes, and are often the last stronghold of threatened species. The need to monitor has increased due to pressures to develop these regions for mining and tourism.

Collecting sufficient land condition data is problematic in remote regions because of the high spatial and temporal variability. Interpreting the meaning of such sparse and minimal data for management decisions is especially challenging because in these highly variable landscapes the response to erratic rainfall and fire events is expressed over long periods of time. There is a need to understand the long term variability, to separate the effects of disturbance, which may indicate a change in landscape health, from those of natural cycles and trends.

Patterns of vegetation growth over the entire Australian arid zone are governed by three key components: total vegetation response, seasonality, and erratic east-west events. This was shown by analysis of 25 years of twice monthly normalised difference vegetation index (NDVI) data, at 8 km spatial resolution. Classification of key components delineated areas of similar variability in vegetation growth at continental scale. The interpretation of these spatio-temporal patterns at regional scale is crucial to enable regional management to separate change due to degradation, from natural variations in growth.

This study focused on the Alinytjara Wilurara (AW) Natural Resources Management region, an area of over 260,000 km^2 in the far west of South Australia. Identification of the spatio-temporal patterns within this region showed that variability in vegetation growth in the AW region is low in the continental context, but within this low response range considerable spatial heterogeneity in vegetation response was found. Seasonal decomposition of time series by loess (STL) analysis of NDVI time series and of rainfall, revealed the cyclic nature of vegetation growth in the AW region, even though STL of rainfall showed rain to be mostly aseasonal.

The classes representing actual vegetation growth showed individual characteristics regarding the average amount of vegetation growth, timing of growth cycles, variability over time and the vegetation type with which they could be identified. For interpretation of monitoring data distinctions could be made between low vegetation growth areas, areas with stronger seasonal effects, areas where vegetation growth was high and temporal variability low, and in the case of cyclonic influence areas where vegetation response was high in some years only. In the north summer rain affected vegetation growth whereas in the south modest winter/spring seasonal response could be detected.

Using actual vegetation response in the classification process enabled the inclusion of all greening in the landscape, which is quite different from the traditional stratification process which is based on static surveys and snapshots in time, and generally only includes perennial vegetation. Comparison with traditional stratification showed that strata previously considered uniform are made up of several actual vegetation growth classes, each with a unique response. This is of importance for selection of field site locations for ecological sampling and placement of comparative monitoring points.

This analysis of spatio-temporal patterns of vegetation growth has shown that Australia-wide variability patterns are also meaningful at regional level. The research provided new, spatially comprehensive information that can be used to improve regional environmental monitoring and management.

Keywords: *Vegetation dynamics, wilderness, interpretation, stratification*

Characteristics of MODIS BRDF shape and its relationship with land cover classes in Australia

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Abstract: Surface Bidirectional Reflectance Distribution Function (BRDF) correction of spectral data (Li et al., 2010) has important applications to time series based analysis and classification. However, it has been reasonably proposed that the BRDF information itself can be used directly in the time series applications for land cover mapping and climate change etc. To use such data it is important to understand the characteristics of BRDF and its variation over different cover and climate conditions and how they relate to well-understood variations in spectral data in terms of the land cover characteristics and changes. Many studies have suggested that BRDF is related to the characteristics of land cover types (Brown de Colstoun and Walthall, 2006 and Jiao et al., 2011), especially to vegetation structure (height and cover) (Lovell and Graetz, 2002; Li et al., 2013) and also climate patterns. In this study, 10 years of MODIS BRDF data sets (MOD43A1) from 2002 to 2011 have been used to conduct an analysis using time series data for land cover data products available in Australia. The data have been averaged over individual years to remove the seasonal patterns and variation for reasons which were outlined in Li et al. (2013) and are briefly discussed later in this paper. Using the "root mean square" (*RMS*, the distance of the shape function from Lambertian which is a measure of its asymmetry) as a BRDF shape indicator, with the inter-annual data series the study has found that:

- The average *RMS* for three bands (red, near-infrared and shortwave infrared) for each year is well correlated with Normalized Difference Vegetation Index (*NDVI*) if it is separated by land cover classes. Correlation coefficients R^2 range between 0.5-0.7. The *RMS* also varies significantly between land cover classes.
- Inter-annual variation of *RMS* is small for typical vegetation classes, especially for classes with high vegetation cover.
- If Normalized Difference *RMS* is used (called *NDRMS,* calculated using red and near-infrared bands and the same formula as *NDVI*), its relationship with *NDVI* is much stronger than that of *RMS*. Correlation coefficients R^2 are close to 0.9 for most of the years. Each land cover class has well defined *NDRMS* patterns. The separation is clearer than for the *RMS* patterns.
- *NDRMS* seems quite sensitive to climate change as indicated by *NDVI* but the relationship over the 10 years in some classes is different from the overall relationship between classes averaged over all years. In vegetated classes, *NDRMS* has tended to increase in this way much more sensitively after the change from a long dry period to wet years, and most particularly after 2009. The sensitivity has apparently increased with class average *NDVI.*

From the above, it has been concluded that:

- Both *RMS* and *NDRMS* are able to differentiate land cover classes defined in the Australian Dynamic Land Cover Dataset (DLCD) series well. They both correlate well with spectral *NDVI* if the patterns are separated by land cover classes and averaged at least over individual years (removing intra-annual effects).
- Both *RMS* and *NDRMS* can potentially be used as additional features to map land cover. However, *NDRMS* seems to be the more sensitive of the two.
- However, confident and successful use of these features will need additional understanding of the sources of the variation and the information they bring compared with traditional spectral data. In particular, further studies are needed to understand the rising sensitivity in *NDRMS* compared with *NDVI* as cover and greenness increase and the previously reported (Li at al., 2013) questions concerning relative phases of intra-annual variation in *NDRMS* and *RMS* relative to *NDVI.*

Keywords: *MODIS, BRDF shape function, land cover*

How generalisable are empirical models to estimate high resolution spatial indicators of crop performance at the regional scale?

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Abstract: Climate change mitigation and adaptation responses in agricultural areas will be a balance between strategies such as the allocation of land to different land uses and changes to current land management. Identification of the spatial variability of production is fundamental to both strategies if efficient area-based decisions are to be made which minimise on-farm economic losses and food security and sustainability issues. Also critical to these strategies is that the information created must be at a resolution high enough to enable on-farm decisions and at extents large enough to guide targeted governmental policy.

This paper aims to address these needs by developing a method for mapping spatial variation in yield at a high resolution across the cropping areas in South Australia.

We developed regression models between satellite-derived Normalised Difference Vegetation Index (NDVI) and yield measured through precision agriculture technologies across three years and compared their predictions with regional yield statistics.

Observations and predictions of district average grain yields ranged from 0.5 to 3.3 t/ha during the study period. The best model efficiency criterion (Nash-Sutcliffe) was 65% in 2005. Our results demonstrate that empirical relationships between high resolution spatial datasets are spatially representative. That is, a model based on the yield-NDVI relationship developed in a very small area can be used to accurately predict regional yield.

Keywords: *Yield mapping, Landsat, prediction, evaluation*

Habitat suitability and susceptibility modeling for strategic control of invasive Buffel grass, South Australia

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Abstract: Invasive plants are a major threat to environmental conservation and are costly to control. To effectively mitigate invasion natural resource managers need to anticipate potential damage, develop policies to prevent introduction as well as mitigate spread. Weed distribution modeling provides managers with the objective information required to strategically direct control efforts. However, often the empirical species distribution data needed to model habitat susceptibility to invasion are limited. For this reason, the benefits of mechanistic models (predictions based on knowledge of species environmental tolerances) are gaining recognition and acceptance. In a recent publication by Smith et al. (2012) a framework for estimating weed invasion potential that utilized expert knowledge of dispersal, establishment and persistence was presented. Here, we construct a model for the contentious weed species, Buffel grass in accordance with the theoretical framework proposed by Smith et al. (2012). This framework distinguishes between habitat suitability and susceptibility. In our study, maps for habitat suitability and susceptibility that incorporate both expert opinion and objective empirical modeling of 2010 Buffel grass roadside survey data are created. Presented are spatially explicit models of introduction pathways, habitat suitability and landscape susceptibility for Buffel grass invasion in the arid zone of South Australia. Results show the relative susceptibility of arid South Australia to Buffel grass invasion. The inclusion of empirical data in this modeling framework presented several challenges, such as the "persistence" indicator, which requires a time component, difficult to quantify empirically. The use of this theoretical framework for spatially explicit modeling requires more thought on how to tackle scale, particularly regarding how the scale of the expert observation lines up with the scale of available environmental data layers, and this is the focus of our discussion.

Keywords: *Habitat suitability modeling, Cenchrus ciliaris, Pennisetum ciliare, weeds management*

An Ecological Footprint Analysis for Illawarra Region (SA2 Level), NSW, Australia

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Abstract: Sustainable development and sustainable construction have become a growing concern worldwide due to ever-increasing awareness of environmental pollution and depletion of natural resources associated with social problems (Chen, et al. 2010). The ecological footprint analysis is a simple and elegant way to determine the degree of sustainability of a defined population. The ecological footprint is defined as the required land to provide natural resources for a population and to absorb the waste produced by that population (Wackernagel *et al*., 1993). This paper presents the results of a detailed ecological footprint analysis of Illawarra region, New South Wales, Australia (at Statical Area Level 2). A map of the study areas is presented in Figure 1.

Results show that inhabitants of Illawarra are consuming way more than the globally available fair share. The results in this paper give a fair representation for the level of unsustainability of lifestyle in Illawarra particularly the level of energy and animal product consumption. Based on the consumption trend presented for the study area in this paper, more than 27 times the existing area is required for Illawarra's population to produce their natural resources and to assimilate the wastes that the population produces. Considering each static area level separately, the highest individual ecological footprint is for an average Australian living in Horsely which consumes 7.65 hectares annually. Based on the results of this study, An Australian person living in Wollongong has the smallest value of ecological footprint (6.27 hectares). Despite the fact that Wollongong has the smallest individual ecological footprint, this area needs the largest area to produce required resources which is because of its larger population compared to other areas.

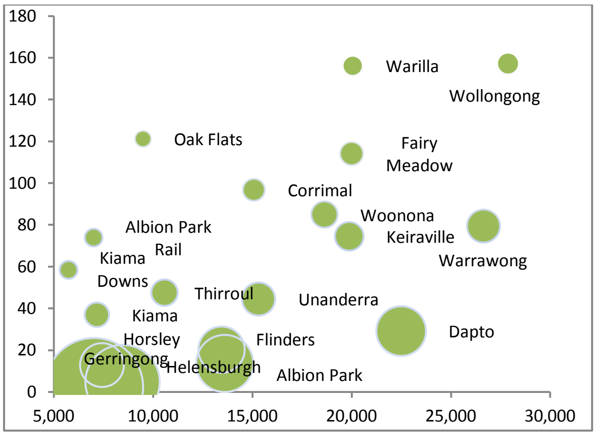

Figure 1: Regional Ecological Footprint Spatial Impact Vs Population Size (Bubble size: Land area in km2); Illawarra Region (SA2 Level)

Figure 2: Ilawarra map, NSW, Australia

The spatial factors are calculated for all the areas to compare the existing land area and the required land area for different areas (Figure 2). It can be seen that Wollongong has the highest spatial factor while having the smallest individual ecological footprint. The reason is the large population and small existing area in Wollongong compared to other areas. Considering Illawarra as a whole, the average spatial impact would be around 27 which means that the required land to produce the natural resources that population in Illawarra needs is 27 times the actual land area of Illawarra. This number can be compared to what Simpson et al. (1998) calculated for South-East Queensland (45), 38 for Canberra calculated by Close and Foran (1998), and 19 for Lower Fraser Valley (BC) calculated by Wackernagel and Rees (1996).

Keywords: *Future Environmental Policy; Ecological Footprint, Sustainable Development.*

New Zealand national and regional nutrient mapping using the CLUES model

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Abstract: CLUES is a GIS-based modelling system which assesses the effects of land use change on water quality and socio-economic indicators. It was developed by the National Institute of Water and Atmospheric Research (NIWA) in New Zealand and is an amalgamation of existing modelling and mapping procedures contributed by various New Zealand research organizations. CLUES allows users to create both land use and farm practice change scenarios (stocking rates, mitigation) using a range of tools. Results are available in map and tabular displays.

Our aim was to model the effects of land use change and intensification on nutrient loads and concentrations in streams in New Zealand, over recent periods of intensification (since 1996) and into the future (to 2020). The CLUES model was run for six scenarios reflecting changes in land use and stocking rates.

Predictions of the spatial distribution of nutrient loading to streams and changes over time are presented. The predicted total nitrogen (N) load (the load entering streams) increased by 20.4% from 1996 to 2020, reflecting both an increase in dairy area and intensification. Overall, N loads increased significantly over time, as a result of both intensification and land use change. Total phosphorous (P) increased initially but decreased by a small amount overall due to the counterbalancing effects of changes in areas of dairying and changes in afforestation.

Regional analysis showed that N loads increased over time in all regions, except that in Auckland and Northland the load decreased slightly from 1996 to 2008, because the area of dairying decreased in those regions, and in Gisborne, N loads decreased from 1996 to 2020, during which time hill country sheep and beef areas decreased considerably and planted forest and scrub areas increased. The largest percentage increases occurred in the Canterbury and Southland regions, and were associated with the large increases in dairying.

P loads decreased only slightly overall nationally, with increases in some regions and decreases in others. In Northland, P load decreased because the area of dairying decreased and the area of forestry on vulnerable soils increased. In Northland, there was also a decrease in P, as sheep and beef areas reverted to scrub. In Bay of Plenty, there was a decrease in P due to the conversion of sheep and beef areas to forestry. In other regions, such as Gisborne and Hawke's Bay, there was an overall decrease in P load, because the effect of increased dairy was outweighed by the effect of afforestation. In areas such as Southland, though, there was an overall increase, due to increased dairying without afforestation, while in other regions such as Canterbury, P load increased due to intensification and increased dairy areas.

The overall implication from a modelling perspective is that land use change and intensification has and will continue to result in increased nutrient loadings and concentrations in New Zealand streams.

Keywords: *GIS, nutrient mapping, CLUES, water quality, N, P*

Using NDVI dynamics as an indicator of native vegetation management in a heterogeneous and highly fragmented landscape

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Abstract: Monitoring change and assessing the impact of natural resource management policies is an important task of regional governments. Remote sensing is routinely used to assess vegetation cover. However, spectral indices record variations in vegetation cover and photosynthetic status, and hence vary substantially with weather. Hence observed changes may largely be due to spatio-temporal differences in climatic conditions rather than management. Monitoring small changes in vegetation cover and extent within a large region requires detecting a small signal in a very noisy environment.

The aim of this paper is to assess the detectability of revegetation sites in satellite imagery. We use an index-trends approach, developed and applied to Landsat imagery of the Adelaide and Mount Lofty Ranges (AMLR) Natural Resources Management (NRM) region at 30 m resolution. Eleven Landsat images (four Landsat-7 ETM+ and seven Landsat-5 TM images) were chosen for analysis, one each from January or February from 2000 to 2010 inclusive. The Normalized Difference Vegetation Index (NDVI) was calculated for each image. During these summer months the contrast in NDVI between dry pasture and weedy grasses and green perennial shrubs and trees can best be detected: most of the revegetation comprises these perennial indigenous species.

We analysed the trends in NDVI, using a linear regression to evaluate the slope of NDVI in the period 2000-2010. The 10 year trend analysis shows potential to detect changes at the scale of the entire AMLR NRM area of almost a million hectares. Comparison of Landsat NDVI trends with known revegetation patches showed that these increases are not detectable after one year, but both native revegetation and dense forestry plantations were demonstrated to be detectable within 5 years of planting. Revegetation in small linear sections (e.g. along creeks or roadsides) remains obscured.

Keywords: *Trend analysis, revegetation, modelling, linear regression*

Defining ecosystem processes of the Australian Great Artesian Basin springs from multi-sensor synergies

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Abstract: The Australian Great Artesian Basin (GAB) supports a unique and diverse range of ecologically significant groundwater-fed wetland ecosystems termed GAB springs. The springs are of great national and international importance for their ecological, scientific and economic values, and are culturally significant to indigenous Australians. The ecological sustainability of the springs has become uncertain in recent times due to increased mining operations and associated groundwater extractions from the GAB. The impacts of existing water extractions from the time of European settlement, pastoral activities and more recently mining are largely unknown. This situation is compounded by the likelihood of future increasing demand of water extractions for mining operations.

The GAB springs are spatially disparate ecosystems located within the arid interior of South Australia, akin to islands in their ecological setting. The springs exhibit a diverse range of geomorphology, hydrogeology, surface expressions and vegetation community composition over a wide range of spatial scales. A suite of remote sensing technologies were used to capture the range of scales of the spring wetlands and their surface expressions. This multi-sensor approach enabled definition of the spatial and temporal responses of dominant plant species, communities and entire wetlands. To validate the suite of satellite and airborne imagery several comprehensive field campaigns were conducted, capturing the variation in spring vegetation communities and surface expressions. This paper provides a review highlighting the sensor synergies that can be drawn from research conducted from the Australian National Water Commission flagship research program, *Allocating Water and Maintaining Springs in the Great Artesian Basin*, which has developed new spatial and temporal tools for monitoring indicators of GAB spring response to water allocations and land use (Lewis et al., 2013). The main objectives of this study included: mapping the location and elevation of western GAB springs using high-precision DGPS; development of protocols for ground-based image validation data; develop techniques for detection and monitoring of the surface characteristics of spring-fed wetlands and surrounding environments using fine spatial and spectral resolution imagery; define the short and long-term temporal dynamics of the springs of indicative vegetation types and entire wetlands; use these remote sensing techniques to provide objective and quantitative information about the spring environments and ecological processes.

The sensors and image analyses employed to address these objectives included: MODIS NDVI time series (annual and seasonal traces of entire wetlands and dominant vegetation types); very high resolution multispectral satellite (detailed delineation of wetland extents using NDVI thresholds) and airborne hyperspectral imagery (detailed discrimination of spring plant communities and surrounding substrate using spectral matching algorithms); supported by concurrent colour digital aerial photography and collection of near-concurrent *in-situ* ecological and spectral data for image calibration and validation purposes. The main focus of this review paper is to draw synergies from the image analyses and research findings that can uniquely be provided using this suite of image data in combination, over differing temporal and spatial scales, to provide new understanding of the drivers and ecological processes underpinning the springs.

The multi-sensor approach revealed for the first time the spatial and temporal responses of these unique ecosystems to changing climatic conditions, land use change and groundwater extractions. Our results reveal that long-term variation is an inherent signature of the wetlands, with distinct phenological responses for differing vegetation species being driven by seasonal temperature and rainfall. In addition the springs were found to change over short time periods (2-3 years) in response to rainfall and land use change, expressed as changing trajectories of outflow channels and inter-connectivity between springs.

This research provides a baseline definition of the long-term natural variation within these groundwater-fed ecosystems as well as their short-term responses to land use changes and water extractions. These outcomes provide an ideal platform for developing models to predict responses of these ecosystems to present local anthropogenic changes in the region and to global climate change.

Keywords: *Spatial indicators, Ecological processes, Remote sensing*

Modelling for the people: Improving the accessibility of landscape scale data sets and raster modelling capabilities in NSW

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Abstract: In the state of NSW, Australia, the State Government, in it's 'NSW 2021' ten year strategic plan, has a target to "*increase the devolution of decision making, funding and control to groups and individuals for local environmental and community activities, including: Catchment Management and Landcare"*. To achieve this target the Government has developed an Information and Communications Technology (ICT) Strategy to improve community access to information and data held in Government Departments. But having access to the best available information and data is only half the story, working out how this information and data should be used to make planning and investment decisions is an even bigger challenge. In 2014 the raster climate surface outputs from the NSW and ACT Regional Climate Model, or NARCliM, climate models of Eastern Australia will become available for the general public to download and use as part of the project. This will generate the need for a user-friendly spatial analysis and data exploration tool to allow non-GIS experts to interrogate these data sets and integrate them with other themes.

This presentation outlines a data management and decision support framework that aims to improve community access to landscape scale spatial data sets, knowledge of ecosystem processes and raster modelling capabilities in NSW. The framework makes use of free software tools that allow for collaborative and interactive development of landscape scale raster models to support decision making. A set of data management standards and spatial data processing tools, for use in ArcGIS, allow streamlining of new spatial data into a format that can be easily picked up and used in the development of spatial models.

The two free and user-friendly applications employed by this framework include; 1) Compendium, customized, dialogue mapping software, to help frame the spatial modelling question and design the conceptual model and 2) the Multi-criteria Analysis Shell for Spatial Decision Support (MCAS-S) software to facilitate interactive data exploration and development of spatial models.

The framework is demonstrated by a case study at the catchment scale that utilises preliminary climate change model outputs to models potential impact of future changes in rainfall patterns on wetland health in the Northern Rivers Catchment Management Authority in NSW. An important feature of the framework, that facilitates adaptive management, is its capacity for ongoing model review and refinement as new knowledge and spatial data sets become available.

Keywords: *Decision support system (DSS), spatial modelling, raster, multi-criteria assessment, natural resource assessment*

A new, more inclusive and interactive approach to modelling spatial priorities for investment in Natural Resource Management in NSW

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Abstract: Catchment Management Authorities (CMAs) were established across New South Wales partly to ensure that regional communities had a say in how natural resources are managed within their catchments. The CMAs are responsible for managing natural resources at the catchment scale and one of their key roles is to prepare Catchment Action Plans (CAPs) to guide investment decisions. Over the last three years the CMAs have been upgrading their CAP documents under guidance from the NSW Natural Resource Commission. The upgrade process requires "*spatial expression of priorities*" and *"use of best available information"* and the identification of where NRM investment will most likely achieve multiple benefits.

Addressing this challenge required the integration of spatial data with scientific expert and local/experiential knowledge. The user-friendly, flexible and interactive Multi-criteria Analysis Shell for Spatial Decision Support (MCAS-S) tool facilitated this integration to build priority setting models. MCAS-S was applied differently by four NSW CMAs as it enabled them to tailor their approach to meet their specific needs as determined by their unique social, political, economic and biophysical landscape.

MCAS-S software has been created by the Australian Bureau of Agricultural and Resource Economics and Sciences through the Australian Collaborative Land Use and Management Program. MCAS-S allows users to visualise and combine raster data layers in a flexible, interactive way. A project can be constructed at any scale and resolution and being interactive and flexible makes MCAS-S an ideal platform for undertaking participatory and adaptive modelling.

The application of MCAS-S in the Hunter-Central Rivers CMA to build spatial models of CAP investment priorities represents a good example of a participatory planning exercise using the multi-criteria analysis approach. A more inclusive and interactive approach also helped to build a common understanding and agreement on spatial modelling objectives and methods.

Four main phases in the spatial modelling process were identified and consisted of; problem definition, data processing, modelling and output. This presentation discusses these phases, the pros and cons of the approach and recommendations coming from it's application in the Hunter-Central Rivers CMA, including:

- The spatial data collation phase was fundamental in shaping the kind of spatial questions addressed in the project.
- MCAS-S model outputs are only as good as the spatial data inputs and some spatial layers were not as reliable or accurate as expected and metadata tended to be insufficient.
- Rapid delivery of spatial datasets to the expert teams was beneficial in prompting individuals to think spatially at a catchment scale particularly for those accustomed to viewing issues as non-spatial theoretical systems or processes.
- The preparation of preliminary models is highly recommended for future projects as it helped to fast track the modelling process.

Keywords: *Decision support system (DSS), spatial modelling, raster, multi-criteria assessment, natural resource assessment*

EXTENDED ABSTRACT ONLY

Using Multi-criteria Analysis Shell (MCAS-S) to rapidly assess soil erosion and flooding amelioration priorities after wildfire

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Abstract: Wildfires, known as bushfires in Australia, can obviously have catastrophic human and ecological impacts. The potential impacts of erosion and flooding when intense rain follows wild fires can be significant and are well documented. Governments in the USA and Australia have set up multidisciplinary emergency natural resources response teams to assess, prioritise and assess costs of immediate ameliorative actions for public safety, protection of infrastructure, flora, fauna, heritage features and water quality. In January 2013 the Wambelong fire which burned nearly 40,000 hectares near Coonabarabran, including 80% of the Warrumbungles National Park. The multidisciplinary Bushfire Area Assessment Team (BAAT) was deployed at Coonabarabran for six days. A feature of the deployment was the use of Multi-criteria Analysis Shell for Spatial Decision Support (MCAS-S) spatial modeling software to assess the impact of sheet erosion hazard 1 in 10 and 1 in 100 probabilities, assessment in changes in runoff and flooding and mass movement, allowing potential impacts to be mapped.

Erosion modelling used pre-prepared RUSLE inputs including: MODIS 2000-2012 ground cover time series; SRTM CSIRO DEM for slope and slope length; K factor soil erodibility based on soil type and surface rockiness from soil mapping; and SILO derived daily 1950-2010 rainfall erosivity. Post fire ground cover was assessed using field observations and satellite fire severity mapping.

Flooding assessments were based on expected changes in interception from vegetation community and litter, changes in soil hydrophobicity. Mass movement hazard was modelled from soil mapping and field assessments

Resulting maps were used by the NSW Burnt Area Assessment Team to help prioritise a series of emergency ameliorative actions.

Within a fortnight of the fire, towards the end of the BAAT deployment, intense rainfall caused severe erosion and unprecedented flooding – immediately validating the predictions.

MCAS-S is a useful tool for rapid natural disaster assessment work because:

- Discipline experts can undertake rapid modelling and adjust inputs as required, matching iterative field observations. This substantially frees GIS operator time for other work
- Google Earth 3d views of outputs, with variable transparency, greatly assists stakeholder visualisation
- Work flow diagrams of connected thumbnail maps helps provide model transparency; Stakeholders can make rapid adjustments; and can readily to add further layers and weightings.
- The MCAS-S project and its data layers can serve as a base for further spatial modelling

MCAS-S rapid deployment success factors include:

- MCAS-S operation by field embedded discipline experts consulting with local discipline experts
- Preparation of relevant all datasets in MCAS-S formats at appropriate scales and tested documentation
- Access to broadband and available office based GIS operators who can arrange and transmit additional datasets as required
- Embedded modelling within an institutionally recognised and timely decision making framework, facilitated by leaders who liaise with stakeholders. This greatly facilitates stakeholder receptivity and the use of model outputs.

Keywords: *Wildfire, Risk Assessment, MCAS-S, RUSLE, Rapid Decision Support*

Preliminary modelling to determine the extent of sustainability of land management practices within land capability in NSW

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Abstract: A key natural resource management target for NSW is managing land within its capability. Land management practices are activities undertaken during the course of land use eg burning stubble, mustering stock or adding fertiliser. A site based system to assess if land is managed within capability was devised in 2008. It compares the biophysical capacity, or capability, of land to withstand potentially degrading impacts of relevant land management practices. To do this land and soil capability class ratings are compared against established upper sustainable land capability limits of land management practices.

Whilst assessments of the sustainability of land management practices have been assessed on a site by site basis, the areal extent of land management within capability has not been possible due to difficulties in obtaining and matching land management practice data against land capability mapping. This paper outlines the methods used to harness Australian Bureau of Statistics (ABS) land management survey 2010 data and compare the outcomes against land and soil capability mapping.

By 2010 Land and Soil Capability was mapped across NSW by using rules to allocate one of eight separate classes to eight separate land and soil capability hazards for each soil mapping unit. The land degradation hazards include water erosion, wind erosion, soil acidification, soil structure decline and salinity.

The ABS was commissioned to report the results of their land management survey according to summarised multivariate clusters of land and soil capability. The summary was necessary because of ABS requirements to maintain anonymity of survey respondents. 30,000 land and soil capability signature combinations were summarised into 8 separate spatially extensive land capability cluster types using multivariate cluster analysis. The clusters were well explained by PCA and relate well to soils and landscape distribution patterns within NSW.

Within each land management cluster the areal extent of upper sustainable land capability limits was then compared against the areal extent of corresponding land management practices. Multi-criteria Analysis Shell Software was used to show the extent to which land management practices contribute towards sustainable land management and conversely to assess how well land is managed against individual land degradation hazards.

Resulting spatial products reveal, for example, that practices relevant to the management of soil acidification are not sufficient to sustain agricultural production for much of NSW. The technique shows promise for determination of sustainability of broad acre management activities for many aspects of natural resource management such as water or native vegetation management.

Expansion of future ABS land management surveys is recommended as this will provide a more comprehensive assessment of the area to which land management is within capability in NSW.

Keywords: *Multivariate classification, Land and Soil Capability, Upper Sustainable Limits, Land Management Practice Assessment*

A large environmental data set and multiple models for decision support in a large scale environmental restoration work – a management perspective

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Environmental restoration attracts research, which results in large datasets and multiple models. Yet, in our experience few such results are useful in planning and management. This presentation aims to study the problems and possibilities in bridging the divide between the science and practice of natural resource management.

Lake Säkylän Pyhäjärvi is located in the centre of an intensive agricultural area in southwest Finland. It is classified as having a good ecological status according to European Water Framework Directive, but this status is threatened by high nutrient loading, which is mostly diffuse load from the catchment. Industrial and municipal waste waters are treated and not directly fed into the lake. The lake supports a fishery, it is used as a drinking and industrial water source, and it is important for recreation. The Lake Pyhäjärvi Restoration Program aims to maintain the good ecological status of the lake in co-operation with many actors. The main topics are the fishery and nutrient load reduction. The program is long-term, large-scale, and intensive, and it has attracted a large variety of lake and the catchment research and modeling projects.

Five anonymous modeling projects conducted in the recent years were selected for self-evaluation. The main criteria were how well did the co-operation and participation work, and how well did the modeling support management.

The projects and the main results are

1. Complex commercial lake ecosystem model. Non-adjustable initial assumptions. – Unrealistic model with wrong assumptions. Unsuccessful co-operation.
2. Complex proprietary phytoplankton model. Flexible and adjustable. – Close and successful co-operation between managers and modelers. Useful model for practical restoration work, creating scenarios for future situations in phytoplankton. Has been used in planning of future management work.
3. Complex freely available lake ecosystem model. Flexible and adjustable. – Could have resulted in useful tool for the management work, but communication failed in the later phase of the project. The model was not properly introduced to managers. The model development was not continued.
4. Very simple lake water quality model. – The model was deemed unrealistic and was not used by the managers because of lack of biological components and food web effect.
5. Complex freely available catchment model that aims to predict the effect of management decisions on water, sediment, nutrient and pesticide yields from large, ungaged catchments. Flexible and adjustable. – Good co-operation between modellers and managers. Deemed useful for planning despite data needs are partially difficult to fulfill.

Our main observation is that the most useful models tend to be complex and very detailed. Models 2 and 5 gave useful perspectives to planning of management work. However, good communication and co-operation between modelers and managers was essential. In our experience, serious communication problems emerge if good data sets are seen as the reason for the modelling. Also, problems arise if a shared view of essential processes to be included in the model is lacking or the model can't be used for the specific needs of practical management tasks. Technology transfer is important as managers have little time to spend for learning new systems, packaged models may be easier to learn, but were poor in bringing about trust and understanding of the underlying conceptualization and maths. Modeling should be seen subjective to the managers' understanding of the system and not as a starting point for management.

Keywords: *Decision support, Management support, Modeling*

Linking ordinal log-linear models with Correspondence Analysis: an application to estimating drug-likeness in the drug discovery process

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Abstract: Ordinal log-linear models (OLLM's) are amid the most widely used and powerful techniques to model association among ordinal variables in categorical data analysis. The parameters of such models are traditionally estimated using iterative algorithms, such as the Newton-Raphson method and iterative proportional fitting. More recent advances involve a non-iterative estimation method that performs equally well for estimation of the linear-by-linear association in OLLM's for a two-way table. This paper establishes a link between the Beh-Davy non-iterative estimation method (BDNI) (Beh & Davy, 2003) and the well-known ordinal correspondence analysis (CA) technique for two dimensional tables. The BDNI estimator of association relies on orthogonal polynomials (OP's), an approach dating from Lancaster (1953) to Beh and Davy (2003). OP's provide insight into the origin and development of non-iterative estimation in OLLM's, as an alternative to popular iterative procedures. The main advantage of OP's is that the resultant parameters enable estimation of the linear, and also quadratic and higher order association structures amongst the ordered categories. Ordinal CA was first introduced by Beh (1997). We compare the linear-by-linear BDNI association procedure with the linear-by-linear association method depicted via graphical representation in ordinal CA. To demonstrate this link and theory we analyzed the relationships between predictors of drug-likeness used in drug discovery to filter out small molecule (drugs) that may fail clinical trials. In vitro absorption, distribution, metabolism and elimination (ADME) assays are now being conducted throughout the drug discovery process, from hit to lead optimization (Kerns & Li, 2008). The analytical community needs still to develop faster and better analytic methods to enhance the 'developability' of drug leads, and to formalize strategies for ADME assessment of candidates in the discovery and pre-clinical stages (Kassel 2004). Assessing drug-likeness depends on the nature of relationships between surrogate measures of drug-likeness (aqueous solubility, permeability) and physicochemical properties (lipophilicity, molecular weight (MW)). To date, lipophilicity is expressed quantitatively as logP, the most popular predictor for permeation. We apply our methods to test rules of druggability (Lipinski 2000). In this study 1,279 small molecules from Hudson *et al.* (2012), based on the DrugBank3.0 database (Knox et *al.,* 2011), a unique chem-informatics resource are analysed. The pair-wise association between categorised variants of 2 of the 4 traditional parameters of Lipinski's rule of five (Ro5), namely MW and logP, and an additional parameter, polar surface area (PSA), introduced by Veber *et al.,* (2002), are shown to differ in magnitude or swap sign across strata, where strata are defined by a molecule's druggable (Ro5 compliant) versus non-druggable (Ro5 violation) status. Log P's association with MW, assumed to be positive, is shown to: [1] change sign from significantly negative to positive for nondruggable *vs* druggable strata, when data is tertiled within the stratum and the first level category (0) satisfies the new cutpoints for violation developed by Hudson *et al.,* (2012), i.e. log P $\leq$1.9 and MW$\leq$305, in contrast to Ro5's cutpoints of log P $\leq$ 5 and MW $\leq$ 500; or [2] be lower (positive) for nondruggable *vs* druggable, for data stratified within quartiles. These findings support recent criticisms about using log P (Bhal *et al.,* 2007) in ADME assessment. Also PSA's association with MW, traditionally assumed to be positive, is shown to change sign from significantly negative to significantly positive for nondruggable *vs* druggable molecules, for data stratified within quartiles; with the first level category (0) satisfying the cutpoints for violation of Hudson *et al.,* (2012), i.e. PSA $\leq$ 65, MW $\leq$ 305, in contrast to conventional cutpoints of 140 and 500, respectively. This study shows that assumed relationships between predictors need to be questioned. Log D, as a distribution coefficient (Bhal *et al.,* 2007), may be a better surrogate than log P.

Keywords: *Ordinal log-linear model, Non-iterative estimation, linear-by-linear association parameter, ordinal correspondence analysis, Lipinski's rule of 5 (Ro5)*

Modelling of links from a laboratory test result to real-world performance: The case of pedestrian collisions

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Abstract: ***Background***. Hardware, software, and people are often tested in one set of conditions, but are expected to perform under many different circumstances. For example, consider pedestrian headform testing. An approximate sphere, with an accelerometer inside it, is projected at the front of a car. The speed is specified, but real pedestrian impacts are at a wide range of speeds. The headform mass is specified, but real pedestrians have a range of effective head masses. The acceleration trace is summarised in order to check that the car is not overly injurious if a pedestrian is struck. This paper will set out the principles of calculating the real-world consequences --- that is, averaged over the range of speeds and effective head masses --- of a particular test result under specified test conditions. Such a calculation is not common in the road safety world, and we do not think it is common in other testing contexts. It is a specific example of the more general problem of using performance in particular test conditions to estimate average real-world performance. (But note that the discussion is not primarily about going from one condition to another, such as from harsh conditions in which failure is accelerated to normal conditions in which failure is infrequent. At least in our context, the test conditions are realistic. The issue is rather that of averaging over a variety of conditions.) ***Proposed procedure***. It is proposed to calculate an estimate of the average level of performance --- averaged over different conditions, that is. This calculation has three components. (1) An equation for the dependence of performance on conditions. (2) An equation for the cost of (i.e., how bad or good are) different levels of performance. (3) The probabilities of different conditions. The three components come together in a summation or integration that represents the averaging over different impact conditions. ***Applications***. The equation permits, for example, the calculation of the changes that result if test performance is improved, or the probabilities of different conditions change. This paper will present the specific methods we have developed, and will suggest they can be expressed in quite general language. Our interest is in impact testing, but the core issue --- the implications for average real-world performance of a test in one set of conditions --- must be in the minds of people concerned with a great variety of tests.

Keywords: *Average severity, Cushioning, Impact testing, Pedestrian subsystem testing, Speed of impact*

The modelling of carious lesion progress

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Abstract: A carious lesion in the tooth enamel is a result of a chemical reaction between mobile organic acids and static hydroxyapatite. Hydroxyapatite is the main component of human tooth enamel, whereas, organic acids are produced in dental plaque by oral microorganisms which metabolize simple sugars from the diet. The organic acids can be transported into the enamel in a dissociated or undissociated form, which depends on the pH of the dental plaque. The transport of ions is diffusive and is motivated by the small diameter of the hydrogen ions compared to the size of the enamel tubules, whereas, when large acid molecules move into the enamel, subdiffusion occurs.

Diffusion is a natural process involving the spontaneous spreading of a substance. Diffusion is characterized by the time dependence of the mean–square displacement of a random walker $\left\langle(\Delta x)^2(t)\right\rangle = D_\alpha t^\alpha/\Gamma(1+\alpha)$, where α is a diffusion parameter, D_α is a diffusion coefficient measured in the units of m^2/s^α and $\Gamma(x)$ denotes the Gamma function. For $0 < \alpha < 1$ we are dealing with subdiffusion; for $\alpha = 1$, we have a situation of normal diffusion, and for $\alpha > 1$, we encounter superdiffusion. Subdiffusion occurs in media in which the movement of the random walker is strongly hindered due to the complex structure of a medium and subdiffusion occurs—among other things—in porous media or gels.

Equations describing the subdiffusive transport of acid molecules and their reaction with static hydroxyapatite are nonlinear partial differential equations with the Riemann-Liouville fractional time derivative

$$\frac{\partial C_A(x,t)}{\partial t} = D_\alpha \frac{\partial^{1-\alpha}}{\partial t^{1-\alpha}} \frac{\partial^2 C_A(x,t)}{\partial x^2} - R_\alpha(x,t)\ , \tag{1}$$

$$\frac{\partial C_B(x,t)}{\partial t} = -R_\alpha(x,t)\ , \tag{2}$$

where C_A denotes the concentration of a mobile substance A, C_B—the static substance B and the reaction term takes the form

$$R_\alpha(x,t) = \frac{\partial^{1-\alpha}}{\partial t^{1-\alpha}} k C_A(x,t) C_B(x,t)\ , \tag{3}$$

and k is the reaction rate constant. For $\alpha = 1$ we obtain equations describing a normal diffusion–reaction system. As far as we know, the general solutions, i.e. for arbitrary parameter values, to (sub)diffusion–reaction equations have not been found yet. Thus, in order to simplify the calculations, various approximations, such as the quasistationary approximation, the scaling method, or the perturbation method, are used. Employing these methods, characteristic functions of the system can be derived which include, among others things, the time evolution of the reaction front which can be identified with a lesion depth.

Using the perturbation method we find approximate solutions to the normal diffusion–reaction equations which are quite satisfactory in comparison with experimental data. We will also find that the time evolution of the lesion depth in the cases of acid transport, normal diffusion and subdiffusion, is a power function of time $x_f \sim t^{\alpha/2}$. This result is also in accordance with the experimental data.

Keywords: *carious lesion, normal diffusion–reaction process, subdiffusion–reaction process, perturbation method, scaling method*

On issues concerning the assessment of information contained in aggregate data using the F-statistic

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Abstract: The analysis of aggregate data has been gaining momentum in the statistics and allied disciplines, (including public policy, political science and epidemiology) for more than 20 years. As a result, the issue has received an increasing amount of attention by categorical data analysts. Performing aggregate data analysis is quickly becoming unavoidable in many situations, especially when individual level data is unavailable. For example, the U.S. Justice Department uses aggregate data to formulate the public policies against racial discrimination, political scientists are always interested in exploring the political or ideological preferences of different demographic groups while social scientists use aggregate data to study the relationship between crime and unemployment. The availability of aggregate data has increased due to strict confidentiality restrictions imposed upon by government and corporate organisations who are reluctant to release individual level information. There is a wealth of contributions on this issue that is available in the ecological inference (EI) literature which considers the association structure between categorical variables (at the individual level) given only the aggregate information. The main difficulty in EI arises due to the loss of information during the process of aggregation and results in aggregation bias. It is also a matter of concern for aggregate data analysts that the interpretation of the parameters from EI models might be entirely different to analogous parameters for the study of individual level data. An alternative strategy to EI is to consider the recently proposed *Aggregate Association Index* (AAI) that allows the analyst to quantify the overall extent of association between two dichotomous variables given only the aggregate, or marginal, information of a 2x2 table. Unlike EI, the AAI does not estimate, or model, the conditional proportions but focuses instead on gauging the extent of association between the variables. The AAI can also be further partition into positive and negative association terms thus enabling the analysts to understand the more likely direction of the association given only the aggregate data. However, the major issue with the performance of AAI is the impact the sample size has on its magnitude. In this paper we investigate the informativeness of the aggregate data for inferring an association exists between the variables of a 2x2 table. This article introduces development of an F-test to determine the statistical significance of the information contained in the aggregate data for inferring a statistically significant association between the variables. Unlike Pearson's chi-squared statistic, the F-statistic is robust to any change in the sample size and depends only on the aggregate information in the contingency table. Thus this statistic provides an opportunity to understand the structure of a 2x2 table without being influenced by sample size. The applicability of this test is demonstrated by using the Selikoff's (1981) asbestosis data which was collected from 1117 insulation workers of New York City in 1963 to explore the links between asbestosis and occupational exposure to asbestos fibres. Such work was the key to establishing the link between asbestosis and mesothelioma. As a result of findings of this nature, many international government organisations have now banned the production, and importation, of goods that contain asbestosis fibres.

Keywords: *Aggregate data, Aggregate Association index, Selikoff's data*

Modelling weight of a Newborn based on baby's characteristics for low birth weight Babies

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Abstract: Neonatal mortality rate (NMR) is an increasingly important public health issues in many developing countries. Neonatal death now accounts for about two-thirds of the eight million infant deaths that occur globally each year. It is well-documented that low birth weight (LBW) is the most significant factor influencing NMR. This paper deploys multi-regression models to identify the significant factors for forecasting the weight of the LBW babies. The model explores the relationship between weights, baby's characteristics, gestation age and mother pre-pregnancy BMI. The results indicate that 65.9% of the variations in the weight of the LBW babies can be explained by baby's characteristics such as the height, head and chest circumferences, the gestation age and mother's BMI. The proposed model was then used to estimate the recorded weights together with their corresponding 95% confidence and predication interval. Analysis of the prediction errors shows that the mean prediction error for the recorded data is one gram. The research is based on a case study in Indonesia intended to improve the mortality rate.

Keywords: *Multivariate simulation, multivariate regression, neonatal mortality rate*

Using Surveillance Epidemiology and End Results data to explore breast cancer mortality trend in an underserved population of Alabama, USA

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Abstract:

BACKGROUND

Although Deep South Network for Cancer Control (DSNCC) was implemented to reduce the breast cancer mortality by increasing awareness and screening, its effect on cancer outcomes has been difficult to assess. Our objective is to explore temporal trends in breast cancer mortality with the implementation of DSNCC using Surveillance Epidemiology and End Results **(**SEER) data.

METHODS

We compared the trend in breast cancer specific and all-cause mortality for Black female breast living in DSNCC target counties using SEER data. We also compared trends in the mortality among DSNCC Black females with those in NON-DSNCC counties. The Health Disparities Calculator (HD*Calc) was used to calculate the association of the DSNCC with mortality.

RESULTS

From 1990 to 2009 there has been a general decrease in breast cancer mortality rates in both DSNCC and non-DSNCC counties, where the DSNCC counties have higher mortality rates. In terms of all-cause mortality the DSNCC counties had overall higher rates. After the year 2000, both DSNCC and non-DSNCC counties saw a decrease in all-cause mortality rates. From 2005 to 2009 the rates of all-cause mortality was significantly lower in the DSNCC than non-DSNCC (RR=0.94; 95%CL= 0.97, 0.91).

CONCLUSIONS

Breast cancer-specific and all-cause mortality among Black females in DSNCC-targeted counties have decreased subsequent to implementation of the DSNCC. These changes were similar to those seen nationally. The population-level trend observed in our study suggest that the DSNCC program may be contributing to a decrease in breast cancer mortality, particularly in early years post implementation among Black females in historically underserved areas of Alabama.

Keywords: *Breast cancer mortality, Deep South Network for Cancer Control, Black females*

Updated meta-analysis of comparison of mortality in enteral feeding (EN) vs. parenteral nutrition (PN) or other methods in gastrointestinal cancer patients

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Abstract: Clinical trials and meta-analyses investigating the effect of enteral nutrition (EN), parenteral nutrition (PN) or other methods of nutritional support are at best confusing with multiple endpoints including major and minor complications as well as mortality. Most deal with a combination of diagnoses such as Crohn's disease, head trauma, liver disease, pancreatitis, various cancers, etc. and neglect to present separate results by diagnoses causing one to seek out the source documentation. There is no up to date comprehensive meta-analysis of EN vs. other methodologies in gastrointestinal (GI) cancer. The goal here is to compare EN vs. alternative methods in GI cancers only with respect to mortality endpoint.

A systematic literature (clinical trials and meta-analyses) search was performed for EN for the past 20 years using Pubmed, Medline, Cancerlit, Embase Cochrane collaborative plus other sources. Randomized clinical trials comparing EN to PN or other methods such as "nil by mouth", intravenous crystalloid solutions, and other oral supplementation were identified. The focus of the search was on articles from the cancer and clinical nutrition literature as well as abstracts and proceedings. This yielded about 14 such publications (1995-2012) with adequate data used in this analysis. Four studies had no deaths in both groups and are not presented here. The primary endpoint for our meta-analysis was incidence of mortality given the raw death incidence and sample size. Many publications provide information on the reduced risk of death of one intervention vs. the other which could be put into a meta-regression with the accumulated data from other publications.

We used a Bayesian random effects model to account for heterogeneity across the studies. However, considering the restricted diagnosis of the subject pool and the similarity of treatment approaches, heterogeneity was not anticipated to be significant. The priors used were non informative and conjugate on the prior mean and variance of the odds ratio (OR) yielding a distribution for both the odds ratio and the predictive odds ratio. We also investigated plots of the distributions of these statistics.

Of the data analyzed , the odds ratio (OR) of mortality in GI cancer of EN vs. other methods is about 0.819 with 95% confidence interval CI, (0.571,1.174) and the predictive OR is about 0.893, with 95% CI (0.546, 1.230). The posterior distributional plots of the OR and predictive OR yield interesting patterns over the studies. The heterogeneity as anticipated was non-significant.

Assuming a wide distributional effect of EN over other methodologies there appears to be a consistent trend that, although EN is preferred because of other reduced morbidities in many publications, the effect on overall mortality of the reduced risk evidenced by this analysis is not statistically convincing across studies. However, using a Bayesian analysis, the posterior probability of the OR being less than one (in favor of EN) ranges from 0.811 to 0.99 and the predicted OR being less than one ranges from 0.544 to 0.888 for realistic prior ranges of the OR over time. On a final note, although EN is superior to other methods with respect to mortality, the effect of this superiority has appeared to decrease over time as seen in the last plot of this manuscript.

Keywords: *Enteral Feeding, Parenteral Nutrition, Gastrointestinal Cancer, Clinical trials, Meta-Analyses, Bayesian Random Effects, Odds Ratio.*

A Multilevel Analysis of Child Chronic Undernutrition in Bangladesh

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Abstract: The sampling methodology based on hierarchical structure of the administrative units creates nested data which enforce to deal with the hierarchical statistical methodology capturing the variation among different levels of hierarchy for a particular phenomenon. Since children are nested from lower (community) to upper (division) hierarchical units chronologically, the theory of multilevel analysis is mandatory for modelling prevalence of child undernutrition instead of standard regression model. The aim is to modelling the prevalence of child chronic undernutrition in Bangladesh and to identify the risk factors through a multilevel logistic regression model. Also find out an efficient multi-level model which can be utilised for predicting prevalence of child undernutrition at lower administrative level such as sub-district using area-level small area estimation (SAE) method.

The study utilizes data from 2011 Bangladesh Demographic and Health Survey (BDHS) and 2011 Bangladesh Population and Housing Census. The analysis is based on 7646 children (having valid anthropometric data) lived in 600 communities across 396 sub-districts, 64 districts and 7 divisions. Community level contextual covariates are created from the BDHS, district level covariates from the Census, and divisional level data from Bangladesh Bureau of Statistics reports. Explanatory variables from survey data are constructed in the similar form of Census so that the fitted model can be utilized for prediction. Height-for-age (HAZ) anthropometric Z-score is utilized as the measurement of chronic undernutrition. A child with less than -2.0 Z-score is considered as undernourish. Standard maximum likelihood method with numerical integration has been applied for fitting both univariate and multivariate multi-level logistic regression model considering children, community (cluster), district, and division as chronological hierarchy. The analysis is done using software R (Package lme4 & VGAM).

The variations in prevalence of child chronic undernutrition in Bangladesh at different administrative hierarchy are checked through likelihood ratio-test for justifying the validity of using multi-level logistic regression model instead of ordinary individual level logistic regression model. Though maximum variation is at individual level, community level (5.69%), district level (0.70%) and division level (0.99%) variations were found significant. Consequently four-level univariate and multivariate logistic regression models are fitted. Univariate logistic regression analyses have been done for selecting the significant covariates which are then used in the final multivariate multi-level logistic model. Covariates at all the four levels are included in the model to reduce variations at all levels for prediction purpose (between-cluster variation <1.0% in final fitted model). Significant covariates are at individual level: child age, mother's education, household wealth status and environmental condition such as housing pattern & sanitary facilities; community level: residential place, women's education status, health facility services such as distance to nearest clinic/hospital; district-level: average household size, literacy rate, population density, urbanisation; at division level: poverty rate, frequency of natural disaster occurrence during last five years. In multivariate model most of the higher level covariates were found insignificant, however significant influences in univariate model. Most of the selected individual and community level covariates were determined as the significant risk factors, especially mother's education, household wealth status, community health services.

The results of the multilevel analysis suggest that community level instead of district-level and/or sub-district level interventions are required for reducing micro-level child chronic undernutrition which must help to mitigate overall child nutrition vulnerability in Bangladesh. For further research, the fitted multi-level model can be used to predict the prevalence of child undernutrition at any lower administrative level using SAE method if all the significant covariates are available at individual level and administrative levels from population census or other sources like GIS.

Keywords: *Child chronic undernutrition, contextual variable, logistic regression, multilevel modelling, prediction*

Trends in waist to thigh ratio among adults in US

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Abstract: The burden of obesity is increasing in the US. Waist to thigh ratio has been proposed as a measure of central obesity. Waist thigh ratio (WTR) has been proposed as an index for abdominal (central) obesity. Epidemiological studies have demonstrated that an increased WTR is a strong predictor for type 2 diabetes and ischemic heart disease. WTR can be used as an inexpensive screening tool to detect unhealthy body shapes and to provide these individuals with the appropriate management to decrease their risk for heart disease and diabetes. Changes in waist to thigh ratio over time in representative samples of US adults were not examined before. Our objective was to examine temporal trends in waist thigh ratio among US adults. Analysis of data collected from 30,001 adults (>=20 years old) who participated in the National Health and Nutrition Examination Survey from 1988 to 1994 and continuous National Health and Nutrition Examination Surveys conducted between 1999 and 2006. The crude and age standardized waist to thigh ratio means increased among males, females and different age groups between 1988 and 2006. Age, gender, race and time were statistically significant predictors for waist thigh ratio (P values<0.01). These results document the increase in abdominal obesity among U.S. adults between 1988 and 2006. Efforts should be made to slow the increasing waist thigh ratio among in the US population.

Keywords: *Epidemiology, Obesity*

A Model for Assessing the Association in the Repeated Measures of Depression among the Elderly

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Abstract: The dependence in the outcome variables is a major issue of concern in modeling the correlated data stemmed from the repeated observations. The marginal models such as GEE and the conditional models based on Markov chain have been employed for longitudinal data in the past. However, it has been evident that without addressing the underlying association parameters, the analysis of repeated outcome variables remains far from being resolved. In this paper, a method has been demonstrated to model such data using the underlying dependence in the outcome variables as well as dependence between outcome and explanatory variables. An extension of the regressive model is shown in this paper and a comparison is demonstrated between the existing model (reduced model) and the proposed model (extended model). The models are illustrated for depression among the elderly population in the USA using the Health and Retirement Study data from 1992 to 1998.

Keywords: *Bivariate binary outcomes, Conditional model, Joint model, Marginal model, Regressive model, Transition probability*

The impact of spatial scales on discretised spatial point patterns

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Abstract: Spatial data are common in health sciences and are available at various spatial scales such as the point, grid or area level. This research considers modelling of point level data, which in practice could resemble disease data with exact residential locations, by discretizing the study region into regular grid cells. Modelling of health data at the grid level is desirable as it is geographically more accurate than using area level data and yet protects patient confidentiality. The challenge is to specify an appropriate spatial scale for discretization of point patterns. We investigate how changes in grid cell size affect model outcomes for various structures of spatial point patterns. A Bayesian spatial model is used to evaluate the impact of varying spatial scales on model outcomes. Estimation is based on a Bayesian spatial smoothness prior to model spatial dependence of neighboring grid cells, namely an intrinsic Gaussian Markov random field (IGMRF). Bayesian computation is carried out using integrated nested Laplace approximation (INLA). The impact of varying spatial scales is studied in a simulation study. The simulated data consist of various spatial patterns that resemble different patterns of point level health data in realistic settings, including inhomogeneous point patterns, patterns with local repulsion, patterns with local clustering, and patterns with local clustering in the presence of a larger-scale inhomogeneity. The evaluation criteria used in this study include the spatial correlation coefficient, the coefficient of variation of the spatially structured effect, and the mean squared error between the observed counts and the estimated counts. Based on the results, we note that complicated spatial patterns such as inhomogeneous point patterns and spatially clustered patterns tend to be more sensitive to the changing spatial scales, compared to homogeneous point patterns. It is therefore recommended to repeat the spatial analyses at multiple spatial scales in order to determine the best scale to analyze the data in order to address the inferential aims of interest. In particular, it is noted that fine grid cell sizes do not necessarily improve inferential outcomes as there has to be sufficient information in the grid cells.

Keywords: *Grid level modelling, integrated nested Laplace approximation, intrinsic Gaussian Markov random field, spatial scale*

Increased Risk of Childhood Brain Tumors among Children Whose Parents had Farm-Related Pesticide Exposures during Pregnancy

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Abstract: Malignant brain tumors rank second in both incidence and mortality by cancer in children, and they are the leading cause of cancer death in children. Relatively little is known about the etiology of childhood brain tumor (CBT). While there are several studies which link pesticide exposure to increased risk of CBT, findings have been inconsistent. We performed a meta-analysis on 15 published epidemiological studies to test that in utero exposure to pesticides may be involved in the development of brain cancer in children. Meta-analysis was performed using the general variance-based method and homogeneity was tested by means of the Q statistic. Summary relative risk (RR) estimates were calculated for childhood brain cancer from 1) paternal exposure to pesticides prior to conception, 2) both maternal and paternal exposure to pesticides during pregnancy, 3) maternal exposure during pregnancy to: a. agricultural and b. non-agricultural activities, and 4) childhood exposure to: a. agricultural and b. nonagricultural activities up to date of diagnosis with CBT. The Comparative Toxicogenomics Database (CTD) was used to identify gene-pesticide-CBT interactions. Findings of meta-analyses revealed a significantly increased risk of CBT among children whose mothers had farm-related exposures during pregnancy (RR=1.48, 95% CI=1.18–1.84). A dose response was recognized when this risk estimate was compared to those for risk of CBT from maternal exposure to non-agricultural pesticides (e.g. home extermination, pest strips) during pregnancy (RR=1.36, 1.10–1.68), and risk of CBT among children exposed to agricultural activities (RR=1.32, 1.04–1.67). Three studies combined for the paternal exposure to pesticides during preconception produced a calculated summary risk estimate of odds ratio (OR) = 2.29 (95% CI: 1.39 – 3.78). Meta-analysis of five studies of paternal exposure to pesticides during pregnancy produced a final calculated summary risk estimate of OR = 1.63 (95% CI: 1.16 – 2.31). The search of the CTD databases revealed association between herbicide and astrocytoma and more than 300 genes are altered by exposure to herbicide, fungicide, insecticide or pesticides. In summary, comparing results from our categories of exposure, pre-conception and pregnancy exposure estimates were slightly higher than childhood exposure estimates, paternal exposures produced slightly higher risk estimates compared to maternal exposures, agricultural exposures produced slightly higher risk estimates compared to non-agricultural exposures and CTD search revealed potential genes-pesticides-astrocytoma interactions. Based on the collective results of these meta-analyses it appears that pesticide exposure may increase risk of CBT, with preconception and prenatal exposures being especially important factors in increasing risk of its development. Interestingly, paternal exposure may be as important, if not more important than maternal exposures, particularly during the preconception period. Whether this is a result of paternal exposures being more prevalent than maternal exposures or the consequence of a biological process, is a question that deserves further attention in future investigations of CBT etiology.

***Keywords**:* *Childhood brain tumor (CBT), Pesticide exposure, Increased risk*

Modelling hospital systems: optimising patient flow, discharge timing and resource allocation

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Abstract: Hospitals now need to meet a number of patient admission targets. In particular, the National Emergency Access Target (NEAT) requires that by 2015, over a calendar year, 90% of emergency department patients are admitted, transferred or discharged within four hours of admission. Targets are around 70% to 80% in 2013/14 but many hospitals struggle to meet them.

Two approaches to improving NEAT performance are to increase bed allocations across wards/units and to discharge patients earlier. We describe an optimisation-simulation model used to find the bed numbers needed to meet the NEAT targets and a simulation model used to investigate NEAT performance for different discharge time scenarios.

The first model used a discrete event simulation of individual patients admitted to inpatient beds from the Emergency Department (ED). The arrival times, ward admissions and lengths of stay were based on patient records from a large teaching hospital. The simulation used a full year of patient admission data to look at how changing the numbers of beds allocated to the wards for different medical speciality groups affected the waiting times for inpatient beds. Specifically, the model was used to count the percentages of patients discharged in four hours or less from the ED to an inpatient speciality bed. The simulation was controlled by an optimisation module that adjusted the number of beds in the specialities to find the minimum number of beds needed to achieve a specified NEAT performance for those patients admitted from the ED.

The second model also used a discrete event simulation of patient flows to evaluate the effects of different discharge time targets on NEAT performance. This model used patient arrival, transfer and length of stay data from a different teaching hospital. The patient flows were more complex than in the first model; they involved detailed transfers between acute and sub-acute inpatient wards and included elective as well as emergency patients. Different scenarios were set up for this model by adjusting patient discharge times where possible (for example, the times for discharge categories such as death were not changed). A given scenario was characterised by a number of daily discharge times and the percentages of patients to be discharged by each time. Again, the model was run using a full year of patient admissions.

Our presentation describes the development of the two models and the results, allowing for sensitive patient and hospital data, obtained from them. We conclude by considering how effectively the two approaches, bed allocations and discharge strategies, can help to improve NEAT performance.

Keywords: *Patient flow, optimal bed allocation, patient discharge timing, heuristics*

Integrative biostatistical approach shows better performance in missing data analysis using longitudinal study of pediatric head trauma

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Abstract: Missing data are a prevailing problem especially in longitudinal studies. A case of a variable is considered missing if the value of the case of the variable for the case is not observed, usually in random. There are many different imputation methods to use for missing data analysis. However, noticing that longitudinal studies measures variables over time, time is a key aspect that we can utilize in missing data analysis. Thus, we propose two Markov Bayesian imputation methods that incorporate time into the process. We propose imputation method based on first degree Markov – the model that impose causal relationship only between immediately adjacent time points – model and second degree Markov – the model that impose causal relationship between immediately adjacent time points and two time points before or after -- model. We also use Bayesian networks, a widely used probabilistic graphical method to express relationships (including that caused by time) among the variables, to implement those Markov imputation models (we call them Integrative Markov Bayesian Method (IMBM)).

To compare the IMBM imputation performance, we compare them with widely used missing data analysis methods – simple averaging and Expected Maximization (EM) – using data collected from a longitudinal study of child and family functioning after pediatric head trauma. We selected group of three variables that were measured in different time points from the original dataset from the longitudinal study. We then remove all the missing cases of the three variables, resulting in a complete dataset with no missing data.

We then randomly selected different portions (20%, 30%, and 40%) of the complete dataset to be randomly missing and report how each missing data analysis method performs in predicting the selected missing cases. We show that even with high (≥ 30%) missing rate for each variable, selecting proper subset of variables and using the relationships among them – that they were measured in different time points – integrative Markov Bayesian statistical methods better estimate the distribution of the missing data that are missing at random. Especially, IMBM with first degree Markov model performed surprising well, resulting in a method that could be easily scaled up to be used in imputation methods for a very large longitudinal studies.

Keywords: *Missing Data Imputation, Expected Maximization, Bayesian Markov Models*

Logistic Regression and Bayesian Approaches in Modeling Acceptance of Male Circumcision in Pune, India

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Abstract: Discernment analyses in survey data are being developed to help researchers better understand intentions of surveyed subjects. These models can aid in successful decision-making by allowing calculation of the likelihood of a particular outcome based on subject's known characteristics. There are many modern discernment analyses which have been used to develop predictive models in many different scientific disciplines areas. Predictive models are used in a variety of public health and medical domains. These models are constructed from observed cases, which are typically collected from various studies. The data can be pre-processed and serve as data to build statistical and machine learning models.

The most frequently used discernment analysis in epidemiological datasets with binary outcomes is logistic regression. However, modern discernment Bayesian methods — i.e., Naïve Bayes Classifier and Bayesian networks — have shown promising results, especially with datasets that have a large number of independent variables (>30). A study was conducted to review and compare these models, elucidate the advantages and disadvantages of each, and provide criteria for model selection. The two models were used for estimation of acceptance of medical male circumcision among a sample of 457 males in Pune, India on the basis of their answers to a survey that included questions on sociodemographics, HIV prevention knowledge, high-risk behaviors, and other characteristics.

Although the models demonstrated similar performance, the Bayesian methods performed better especially in predicting negative cases, i.e., subjects who did not want to undergo medical male circumcision in cross validation evaluations. Since there were less negative cases in the dataset, this indicates with smaller sample size, Bayesian methods perform better than logistic regression. Identifying models' unique characteristics — strengths as well as limitations — may help improve decision-making.

Keywords: *Logistic Regression, Bayesian networks, Discernment analyses*

Combining Structure Equation Model with Bayesian Networks for predicting with high accuracy of recommending surgery for better survival in Benign prostatic hyperplasia patients

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Abstract: Causal discovery is the key aspect of science. Inferring causality can be achieved in various ways. Typically, you start with your hypothesis (based on what you know so far) and based on the data you collect, you update your hypothesis. In a nutshell, causality can be inferred via your background knowledge and empirical data. Causal Both Bayesian networks (BN) and Structural equation model (SEM) are graphical models that are able to model causality both from background knowledge and empirical data. SEM heavily relies on your background knowledge and use data to justify your knowledge. On the other hand, BN can combine your background knowledge with a causal model that gives the maximum likelihood based on data. If the relationships turn out to be statistically significant, then expert's knowledge is considered statistically valid and can be used to provide guidelines in practice using the model based on expert's knowledge.

Functional changes of the bladder are commonly seen in patients with benign prostatic hyperplasia (BPH). We investigated the predictive factors for the alteration in the bladder storage function in patients with BPH using Bayesian networks (BN) and Structure Equation Model (SEM). We analyzed database of consecutive 1,352 patients with BPH who underwent urodynamic studies from Oct 2004 to Oct 2011 in a single institution.

We show that combining BN and SEM enables us to build a data driven prediction model with latent constructs. The BN showed that (1) predicting outcome variables, when TZVol is known TPVol and PSA do not add value in prediction; (2) if we know StoragePhaseDetrusor, then all input variables do not help more in predicting Bladder Compliace; (3) when BladderSensation is known, BOOI plays important role in predicting BladderCapacity and StoragePhaseDetrusor; (4) if we know TPVol then TZVo and PSA are independent.

User Self Reported Condition and Eurodynamic Study Results did not receive significant latent score and all the variables are discrete, BN was a natural pick to model latent constructs. Volume Capability of Patient's Bladder receive significant latent score and all the variables are continuous, SEM was used to model latent. The combined data driven model reveals that bladder outlet obstruction (BOO) increases the risk of secondary bladder storage dysfunction in patients with BPH. This suggests that more aggressive treatment for BOO might be recommended.

Keywords: *Bayesian Networks, Structure Equation Modeling, Benign Prostatic Hyperplasia, Urodynamics, Bladder Outlet Obstruction*

Modelling to improve understanding of Pertussis epidemiology in Australia

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Abstract: In the first half of the 20th century, 3-5 yearly whooping cough epidemics caused a substantial burden of death and disease in Australia. The introduction of mass vaccination in the 1950s dramatically reduced disease incidence, but from the 1980s onwards resurgence of cases was observed among adolescents and young adults, placing vulnerable infants at risk. Despite predictions that shifting the 18 month vaccine dose to the adolescent years would likely reduce overall incidence, this intervention failed to produce the anticipated reduction, and from 2008-2012 pertussis incidence was at its highest since the implementation of vaccination. A dynamic model incorporating contemporary, population-specific data is needed to improve our understanding of pertussis transmission and provide more robust predictions of vaccination impact.

Methods and approach: We developed an age-structured, compartmental, transmission model to define the relative degree and duration of natural and vaccine derived immunity consistent with observed pertussis disease in Australia. Varying levels of susceptibility to infection were included to account for the possible dependence of susceptibility and infection characteristics on the time since prior infection or vaccination. Biologically plausible parameter ranges were explored using Latin Hypercube Sampling and the model simulated with 100,000 different parameter sets. Simulation results were filtered to identify those matching key features of surveillance data in recent decades, including persistence of 3-5 year epidemic cycles, relative maintenance of infant protection and declining natural immunity across all age cohorts.

Findings and interpretation of model output: Initially we assumed that infants were fully susceptible until they had received all three primary vaccine doses. We found very few parameter combinations able to simultaneously reproduce the key epidemiologic characteristics of pertussis in Australia. It was particularly difficult to achieve the large reduction in infant disease observed following the introduction of mass vaccination. With the primary course delivered as three separate doses in the model, many more simulations reproduced epidemiologic patterns than when we assumed full susceptibility until three doses were received.

Only simulations with natural immunity greater than 30 years simultaneously reproduced the adult immunity profiles observed in serosurveillance and the substantial impact of vaccination on incidence. In addition, when naïve susceptibles were more than twice as likely to be infected than previously infected or vaccinated susceptibles, the average duration of natural immunity had to exceed 50 years for simulated results to be consistent with Australia's disease experience.

In the pre-vaccine era, most parameter combinations generated annual naïve incidence approximating the size of the birth cohort, consistent with observations that almost everyone eventually contracted pertussis. The model responded rapidly to changes in vaccination coverage, with incidence plummeting during the 1970s when reported coverage of 96% was applied and rebounding to very high levels when we reduced coverage and removed the toddler booster in 1979. The timing of this increase in our model corresponds to the re-introduction of the toddler booster in the mid 1980s in response to increased pertussis hospitalisations.

Our results provide broad insights into pertussis dynamics and the impact of vaccination, including:

- a single dose of vaccine may provide infants with some direct protection against infection;
- on average, the duration of natural immunity is long (at least 30 years); and
- pertussis dynamics are very sensitive to changes in vaccination coverage.

Conclusions: The natural characteristics of pertussis infection, especially the duration of immunity, appear to be most important in shaping Australia's pertussis epidemiology. Further, changes to the vaccine schedule induce oscillations which take many years to subside. Our model provides a framework to consider how the uncertainty which surrounds pertussis transmission parameters affects the range of possible outcomes of vaccine interventions. Projecting forward all identified parameter combinations capable of reproducing observed pertussis experience will provide more robust predictions of vaccination impact.

Keywords: *Pertussis, vaccination, transmission model, Latin hypercube sampling*

The role of short term population movement in sustaining STI prevalence in remote Australian Indigenous communities

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Abstract: For almost two decades, diagnosis rates of sexually transmitted infection (STI) such as chlamydia and gonorrhoea have been notably higher for residents of remote Indigenous communities than for non-Indigenous Australians. High levels of population movement between remote communities may be a contributing factor in sustaining these high rates.

We developed an individual-based computer simulation model to study the relationship between population movement and the persistence of STIs within multiple small communities. We examine the distribution of infection across locations and the impact of mobility and periodicity on prevalence over a range of location- and time-specific screening interventions.

Our findings suggest that: 1) short-term population movement, along with periodic variations in travel patterns allow STIs to persist at a high level in multiple small populations; 2) infection is not evenly distributed across populations, with more than 80% of infection concentrated at the most populous location, despite this locations only comprising 72% of the total population at a given time; 3) maintaining screening coverage at the current level (44% of population screened annually) in small locations alone has limited impact on STI prevalence in the overall population; reduction in prevalence is unlikely to be achieved unless screening coverage and frequency are increased substantially or screening is expanded to include larger regional centres prevalence is higher; 4) population mobility can influence the outcomes of location- and time-specific screening interventions; interventions should be scheduled to occur during periods of low mobility when individuals are more likely to be at home and have access to local health services.

Keywords: *Mobility, STI transmission, prevalence, screening, Indigenous populations, remote communities, chlamydia, gonorrhoea*

Tiered Prediction System for Preeclampsia: an integrative application of multiple models

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Abstract: For years, it has been a challenge to identify women at risk of Preeclampsia (PE), one of the leading causes of maternal and perinatal morbidity and mortality. This would be especially useful in early pregnancy when modifiable factors can be addressed to reduce the risk or severity of outcome. Despite an increasing number of clinical and statistical prediction models being developed, which have been shown to outperform traditional maternal history or Doppler ultrasound approaches, it is still difficult to make accurate predictions based on a single model at a single time-point. Hence, here we investigate the use of multiple models integrated by Bayes' theorem.

Methods: Prediction models based on three stages of pregnancy, pre-pregnancy, 15 weeks and 20 weeks of gestation, were developed with varying levels of sensitivity and specificity specific to each stage. Post-test probabilities at each stage are then calculated based on the Likelihood of each test using Bayes' theorem. The accuracy measures and predictive values are evaluated for both pre-test and post-test probabilities.

Results: The overall proportion of truly identified cases have improved in the integrated model, with 81% correctly identified at 20 weeks of gestation, compared to 75% by the individual model. A relatively balanced accuracy can be achieved even when individual tests have been specified for higher sensitivity or specificity.

Conclusion: Through an integrated prediction system, the accuracy of prediction is further enhanced and tailored for individual women, as the risk is assessed and updated throughout pregnancy based on predictors at different stages, the likelihood of PE from prediction at earlier stages, and clinicians' knowledge or hypotheses.

Keywords: *Preeclampsia, prediction, Bayes' theorem*

Optimal Procurement with Demand Warning

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Abstract: In the field of inventory management, substantial research has been conducted on the formulation of both prediction and procurement algorithms to meet lumpy unforeseen demands. Often these approaches, based on re-order point methods fall short, generating stock outs when procurement lead times are long or order quantities are constrained. Fortunately, for certain circumstances in the fields of military and commercial planning, there are warnings associated with demand spikes or lumps which can be used in the procurement plan.

In this paper we formulate a dynamic programming approach for the optimal procurement of stock, given warning of a demand spikes based on Advanced Demand Information. The dynamic programs formulated are based on direct rewards, both during the prior warning period and during the demand spike. During the warning period, moderate negative rewards for the procurement of stock are given to avoid the storage of unnecessary stock holdings and during the demand spike, large negative rewards are given to stock outs. The dynamic program model assumes orders take place only after receipt of goods, that is, production is inherently constrained, so multiple orders cannot take place within a single lead time. Consideration of capacity constraints is included in the dynamic program formulation.

Dynamic programs that break this production constraint assumption are formulated, allowing orders between the receipts of goods. This results in a large increase in program dimensionality which is estimated. We discuss extensions to the problem, including stochastic baseline demands, and combining re-order point methods with a dynamic programming 'meta-controller' to ensure inventory sustainability.

Keywords: *Logistics planning, dynamic programming, inventory policy*

Heuristics for Incremental Network Flow Problems

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Abstract: In many infrastructure networks it is necessary to plan for incremental expansion over many years, balancing the capital and operating costs of the network. For long term projects such as freight logistics, transmission grid expansion and urban water networks, the availability and cost of upgrades many years into the future can affect the success of current infrastructure investment. Assuming that reliable forecasts of future costs and options are available, we provide a formulation to optimize infrastructure planning over a long term planning horizon.

We consider an abstraction of this problem in an environment of increasing supply and demand, where existing infrastructure networks must be expanded to meet growth. In our model, arcs may be upgraded over a construction period to increase capacity and improve flow cost. Each time period has a budget for these transition costs. The availability and price of upgrades can vary with time, with several upgrade or construction options for each arc, as well as options for downgrading or refurbishing existing arcs. In each time period, the network provides flow between the supply sites and demand sites, with a cost associated with flow along an arc. We formulate this problem as an integer programming problem and utilize commercial solvers to optimize the total cost over a fixed long term planning period. Furthermore, we also utilize the inherent network structure of the problem to improve solver performance. The problem can be decomposed into a set of linking constraints which bind a global network flow to a local assignment problem for each arc in the network in each time period. In this paper we demonstrate the significant impacts that these decomposition techniques have on the size of problems that can be solved using an integer programming approach. We also discuss the impact that heuristics can have on the solver performance, such as whether "natural" greedy heuristics perform well compared with the optimal solution or other heuristic strategies.

These algorithms are applied to several test problems and allow us to observe whether current heuristics that are commonly used in industry provide a good guideline for infrastructure investment policy. This also provides insight into whether more complex heuristics or integer programming formulations can inform better decision making for large infrastructure planning problems.

Keywords: *Network Design, Infrastructure Planning, Network Flow*

A Conceptual Model for Assessing the Impact of Adopting Condition-Based Maintenance

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Abstract: Condition-Based Maintenance (CBM) involves performing preventive maintenance actions based on evidence of need, rather than more traditional usage or time schedules. The promise of CBM is threefold: to extend the useful life and reduce the through-life cost of equipment, to improve fleet operational availability and mission effectiveness, and to reduce the maintenance burden. While well established in other military domains (particularly Air) and commercial domains, adoption of CBM in the military Land domain has been slow, but is now solidly underway.

It is likely that the introduction of CBM to support Land-based military forces will require the adoption of new technological systems. When anticipating the effects of the adoption of such systems, it is important to consider the associated practices, processes and policies in addition to the technology itself. Quite frequently, factors other than inherent technological merits determine the success or failure of adopting new technologies. The continued successful adoption of Land CBM requires that not only the potential technology barriers be identified and addressed, but also that an appropriate understanding of the nuances of CBM adoption in the military Land domain be attained.

Anecdotally, the two most frequently cited reasons for the slow pace of adoption of CBM within the Land domain are: 1) that different drivers for adoption exist in the Land domain than others such as the Air domain, and consequently 2) the difficulty of establishing a clear business case for adoption in the Land domain. The latter is made more difficult by the former. For example, in the Air domain, safety is the most critical factor and the argument for adoption is clear. Conversely, the consequences of catastrophic equipment failure may at times be perceived as less severe in the Land domain, and hence, the safety argument tends to lose its criticality while more pragmatic economic considerations rise in prominence.

Drawing on a number of established methods and techniques, a general conceptual model has been developed for studying the impacts of the introduction of a new technology and identifying the key drivers and factors that need to be understood for its adoption to be successful. This paper presents the conceptual model developed to describe Land CBM and the initial results of a CBM 'Technology Impacts' study. The intention of this study is to obtain a comprehensive set of cost/benefit factors, clarify the drivers for adoption, identify the areas of most importance to stakeholders, and determine the critical issues that must be addressed in order for CBM to 'work' in the military Land domain.

Following a literature review and a first round of Subject Matter Expert (SME) surveys, a 'causal impacts' map has been established. This map considers the impact of the factors that enable a CBM capability and the likely outcomes of adoption of CBM. In addition, the map captures economic and temporal considerations, impacts on stakeholder groups, and impacts on inputs to the development and delivery of military capability. This map will be further refined and analysed as the study progresses. A second round of SME surveys has been prepared that will elicit responses to refine the structure and content of the causal impacts map, and to clarify the position of participants on impacts where a conflict of opinion has been identified.

The study outcomes will inform planning and investment decisions relating to the acquisition of new Land force equipment, and will contribute to collaborative research within The Technical Cooperation Program. Ultimately this study will form a basis for a 'value proposition' framework to assess the extent to which CBM should be adopted within the maintenance practices of Land-based military forces.

Keywords: *Condition-Based Maintenance, Causal Impacts Mapping, Cost/Benefit Analysis*

Hamiltonian path approach to variable-interval scheduling problems with heterogeneous resources

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Abstract: This paper addresses a specific class of problems in the domain of "Interval scheduling". This family involves situations where a set of conflicting tasks must be optimally allocated to a fixed set of heterogeneous resources. All tasks are constrained to strictly begin at a specified time and resources are only available within limited time windows. Such problems arises in various different contexts including train scheduling, maintenance scheduling, personnel task scheduling for work-force rostering, machine scheduling and even some situations of vehicle routing (such as scheduling of recreational vehicles).

Fixed-interval scheduling has been well studied in the literature. However, the generalized case of variable-interval scheduling (resource dependence in conjunction with sequence dependence) has not received significant attention. Specifically, we consider situations where a sequence dependent change-over effort (cost and time) must be expended by the concerned resource between any pair of consecutive tasks executed by that resource. These intermediate efforts, costs and times depend on the resource being utilized as well as on the preceding and succeeding tasks. We limit our discussion to the objective of minimizing the cost of all resources being utilized for accomplishing all tasks. We expect that a large number of resources are available, with substantial capacity overlap and considerable symmetry of capabilities. The traditional approach of modelling such cases is to use decision variables that will assign resources to the tasks executed by them. However, this approach does not inherently account for the time variability - it cannot capture the inter-dependence of tasks and also cannot model the effect of a given resource being allocated to a pair of tasks.

We propose a new approach based on Hamiltonian path decomposition. Our approach addresses the variability in duration of tasks and also caters to the sequence-dependence aspect. Effectively, we transform the interval-scheduling problem to a variant of the multiple travelling salesman problem (tasks are mapped to nodes being traversed on a graph). We demonstrate that the resulting topology automatically avoids sub-tours and also induces a very sparse graph if the arcs on the graphs correspond to pairs of tasks for which any given resource is qualified. We discuss a combination of exact and heuristic techniques to solve the problem based on this topology. The performance of our approach actually improves when the variability of task-lengths increases. Further, the performance is only slightly affected by the number of resources involved.

Keywords: *Interval scheduling, combinatorial optimization, integer programming, Hamiltonian path*

Data description and categorisation techniques for demand forecasting evaluation

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Abstract: Efficient and effective replenishment of replacement parts for military vehicle fleets requires accurate forecasting of demand. Military fleet management systems often depend upon the use of demand forecasting models to determine the timings and quantities for automated stock replenishment. These models generally rely on data sets of demand history for particular stock items to forecast future usage. The majority of published research into forecasting and replenishment models focuses on algorithm design, model selection, or output performance metrics. What is often ignored in forecasting discussion is the identification of input profiles, a modified demand history representing a time series of data whereby the total number of items of a particular stock type are requested each forecast period (month in this case). The impact this identification will have on the effectiveness of the forecasting methods (ability to predict demand) is not usually measured in forecasting systems.

A simple quadrant system has been used widely over the last decade to categorise demand input profiles, and is based around both the square of coefficient of variance CV^2 and average inter arrival time A_t (in time periods) of these profiles. This system defines four categories for the input profiles; lumpy($CV^2 \geq 0.5,\ A_t \geq 1.33$), erratic($CV^2 \geq 0.5,\ A_t < 1.33$), intermittent($CV^2 < 0.5,\ A_t \geq 1.33$), and smooth($CV^2 < 0.5,\ A_t < 1.33$). Defence demand profiles are generally less smooth and more erratic or lumpy (exhibit a higher coefficient of variance) than most commercial/industrial profiles examined in forecasting literature. This, in the quadrant system, corresponds to demand profiles that are typically more difficult to forecast. Using such sample input profiles we also find that it can be difficult to differentiate efficacy, to any statistical significance, between any of the forecasting models acting upon this categorisation of demand profiles.

In this presentation we seek to investigate the effectiveness of the quadrant categorisation technique in relation to Defence vehicle fleets and propose how this categorisation may be improved. In particular, this investigation provides insight into how adjustments and features (extensions) added to the categorisation technique may suggest a better selection of forecasting models to determine appropriate stock replenishment actions. Some examples include adjustments based on seasonal indexing, variance in arrival time A_t, or extensions that utilise acquisition information such as costing (storing together with purchase price) and lead time (lead time demand). In some cases it can be shown that none of the forecasting models are able to ensure appropriate replenishment behaviour, given certain types of input profiles. In these cases alternative inventory management techniques, such as ad-hoc rule based techniques, may be more applicable. The demand profile categorisation ideally should identify when such instances occur.

A pilot study was conducted with a small sample set of forty distinct stock item demand profiles generated from a Defence vehicle fleet. These profiles were categorised as difficult to forecast yet indicative of all stock items used by the fleet. This sample set was analysed in collaboration with the United States Army Materiel Systems Analysis Activity (AMSAA) organisation in preparation for a more expansive investigation into collections for many whole of fleet profiles. The pilot study results were used to configure suitable adjustments to the categorisation techniques. The modified quadrant system was then applied to the complete set of demand profiles for the vehicle fleet to measure the effectiveness of the changes.

This investigation into demand profile catergorisation techniques and experimentation mentioned could improve decision making in replenishment strategy for Defence fleets. This will in turn aid in improving Defence acquisition and sustainment practices, particularly those that use automated inventory management systems that rely on forecasting techniques to trigger purchase timings and quantities. Hence such research could be of significant cost benefit for military platforms (potentially millions of dollars' worth) given that there are several thousands of items in the exemplar fleet alone with difficult demand input profiles.

Keywords: *Catergorisation, demand, forecasting, replenishment*

Treatment Planning Optimisation for Volumetric Modulated Arc Therapy (VMAT)

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Abstract: In this paper, we study the treatment planning optimization problem of a form of radiotherapy, the Volumetric-Modulated Arc Therapy (VMAT). In VMAT, patients lie on a treatment couch, and radiation is delivered to the patient continuously from a gantry that rotates around the patient in one arc (360 degrees) or in multiple arcs. Mounted to the head of the gantry, there is a multileaf-collimator (MLC) with rows of thick metal leaves that block the radiation from passing through. Each row of a MLC has a left- and a right-leaf, and the leaves move horizontally. Radiation can pass through the opening (aperture) formed by the different left- and right-leaf positions in each row of the MLC. The aperture can change as the leaves move and as the gantry rotates around the patient. The industry practice is to discretise the 360-degree arc into k evenly spaced sections, with the mid point of each section considered as a "control point". Clearly, the larger k is, the more accurately the radiation delivered can be calculated.

The search of the optimal combination of apertures and their associated radiation weights from each control point is clearly a combinatorial optimisation problem. The goal is to ensure that a tumour will receive a desired dose so that the cancer cells can be destroyed, and that nearby healthy organs can be spared from harmful radiation as much as possible. The plan, however, must also satisfy several machinery restrictions.

In this paper, we first present a Mixed Integer Linear Programming (MILP) formulation for this problem, followed by some valid inequalities to strengthen this formulation and polyhedral analysis on an important subproblem. Next, we propose four methodologies for solving these problems: two heuristics based on Lagrangian Relaxation (LR), one heuristic based on a reformulation of the problem, and a metaheuristic based on the Guided Variable Neighborhood Scheme (GVNS).

In the first LR-based method, we relax the machinery constraints that concern consecutive control points, hence resulting in k separate subproblems. The second LR-based method, on the other hand, generates two subproblems, one with only variables that determine the apertures for each control point, and the other the radiation weights for each control point. The two problems are solved individually, after which we perform sub-gradient optimisation to update the Lagrangian multipliers. The third heuristic is a reformulation of the problem where we assume all apertures are symmetric with a common centre in each row of the MLC. This formulation is much easier to solve, and any feasible solution to this problem will be feasible to the original problem. With the GVNS, we integrate a problem-specific feature into the generic Variable Neighborhood Scheme framework. If a solution indicates more over-dose than under-dose we search the neighbourhood by reducing the apertures and/or the radiation weights, otherwise, we increase the apertures and/or radiation weights.

We experimented our methods extensively and studied various aspects of our methods, including their strengths and challenges ahead. Numerical results showed that our GVNS was able to solve problem instances of size comparable to those from real clinical data with up to 180 control points.

Keywords: *Radiation Treatment Planning, Mixed Integer Programming, Polyhedral Analysis, Lagrangian Relaxation, Heuristics*

A Bucket Indexed Formulation for Nonpreemptive Single Machine Scheduling Problems

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Abstract: Nonpreemptive single machine scheduling problems require a set of jobs to be scheduled on a single machine such that each job is processed exactly once without interruption and the machine processes at most one job at a time.

The classical time indexed (TI) integer linear programming model is arguably the most common mixed integer linear programming formulation for nonpreemptive single machine scheduling problems. It has a strong linear programming relaxation and is naturally suited to be included in formulations of more complex problems which are frequently modelled using TI variables. However, the length of the planning horizon is pseudopolynomial in the size of the problem input and for many practical machine scheduling instances the resulting model is often intractable due to the large number of constraints and variables.

We present an exact bucket indexed (BI) mixed integer linear programming formulation for nonpreemptive single machine scheduling problems that is a result of an ongoing investigation into strategies to model time in planning applications with greater efficacy. The BI model is a generalisation of the classical TI model to one in which at most two jobs can be processing in each time period. The planning horizon is divided into periods of equal length, but unlike the TI model, the length of a period is a parameter of the model and can be chosen to be as long as the processing time of the shortest job. The two models are equivalent if the problem data are integer and a period is of unit length, but when longer periods are used in the BI model, it can have significantly fewer variables and nonzeros than the TI model at the expense of a greater number of constraints.

A computational study using weighted tardiness instances reveals the BI model significantly outperforms the TI model on instances where the range of processing times of the jobs is small relative to the mean processing time, that is, the processing times are sufficiently large and clustered rather than dispersed.

We are currently investigating the polyhedral structure of the BI model, as well as extensions to the framework that admit the modelling of even larger buckets, and buckets that are not uniform in size.

Keywords: *Single machine scheduling, mixed integer linear programming, time indexed formulations*

A New Criterion Space Search Algorithm for Biobjective 0-1 Integer Programming

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Abstract: Multi-objective optimisation, one of the earliest fields of study in operations research, has been experiencing a resurgence of interest in the last decade. This is due, in part, to the ever increasing adoption of optimization-based decision support tools in industry. Since most real-world problems involve multiple, often conflicting, goals, the want for multi-objective optimization decision support tools is not surprising. The development of effective, and relatively easy to use, evolutionary algorithms for multi-objective optimization is another contributing factor. Finally, and most importantly, the enormous advances in and cheap availability of computing power. Solving multi-objective optimization problems is highly computationally intensive (more so then solving single-objective optimization problems) and thus the availability of cheap computing power has acted as an enabler.

Algorithms for multi-objective optimization can be divided into decision space search algorithms, i.e., methods that search in the space of feasible solutions, and criterion space search algorithms, i.e., methods that search in the space of objective function values. It has long been argued that criterion space search algorithms have advantages over decision space search algorithms and are likely to be more successful. Our motivation for focusing on criterion search space algorithms is that we want to exploit the power of commercial (single-objective) integer programming solvers. Several powerful commercial integer programming solvers exist, e.g., the IBM ILOG CPLEX Optimizer, the FICO Xpress Optimizer, and the Gurobi Optimizer, and criterion space search algorithms can take full advantage of their features.

In this paper, we focus on biobjective 0-1 integer programs. We present a new criterion space search algorithm, the rectangle splitting algorithm, for finding all nondominated points. The algorithm extends the box algorithm, is easy to implement, and converges quickly to the complete set of nondominated points. Because the algorithm maintains, at any point in time, a diverse set of nondominated points, it is ideally suited for fast approximation of the efficient frontier. In addition, we present several enhancements of the well-known ϵ-constraint, augmented weighted Tchebycheff, and perpendicular search algorithms. An extensive computational study, using instances from different classes of combinatorial optimization problems, demonstrates the efficacy of the rectangle splitting algorithm.

Keywords: Biobjective 0-1 programs, rectangle splitting method, ϵ-constraint method, prependicular search method, augmented weighted Tchebycheff method

Picking Items for Experimental Sets: Measures of Similarity and Methods for Optimisation

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Abstract:

Experimental psychologists often conduct experiments in which subjects are exposed to sets of stimuli. For example, human subjects may be shown a sequence of written words, and their response times recorded in order to understand the effect of one attribute, such as the frequency of the word in spoken language, on human response time. The psychologists designing the experiment will construct several sets of words so that each set contains only words within a specified range of frequencies in the spoken language. To reduce the risk of bias in the experiment, the psychologists would like each set of words selected to be similar in terms of other confounding attributes that could affect response time, such as the number of letters in the word, or the number of syllables. A challenge for the psychologists is that the sets they select may need to contain many words, the words may be selected from a set of thousands, and a large number of potentially confounding attributes may need to be considered. This daunting task, which we dub the problem of *Picking Items for Experimental Sets (PIES)*, is usually performed manually by experimental psychologists.

To assist in this task, both metaheuristic and mixed integer programming (MIP) approaches have recently been developed. Such automated approaches require a systematic definition of "similarity" of sets; the degree to which sets of items are similar with respect to some attribute can no longer be assessed objectively by the psychologist designing the experiment(Forster, 2000). To illustrate this issue, consider two sets of words, B_1 and B_2, where $B_1, B_2 \subseteq W$, the set of words available for selection, and the attribute given by the number of letters in each word. For each word $w \in W$, let f_{wl} denote the number of letters, l, in word w. One approach to measuring the similarity of the two sets is to compare the average value of the attribute across the sets, i.e. measure based on the difference $|\frac{1}{|B_1|}\sum_{w\in B_1} f_{wl} - \frac{1}{|B_2|}\sum_{w\in B_2} f_{wl}|$. However it is well known that very different distributions can have the same average value. For example, defining the attribute value count vectors $\eta_{B_i c} = |\{w \in B_i : f_{wl} = c\}|$ for each $i = 1, 2$ and each positive integer value c that could be the length of a word, say ranging from 1 to 5 letters. This approach would consider two sets with $\eta_{B_1} = (3, 3, 3, 3, 3)$ and $\eta_{B_2} = (0, 0, 15, 0, 0)$ to be very similar, whereas clearly the experience of a human subject to these two sets might be very different: the former has an even spread of word lengths whereas the latter has all words of identical length. The existing metaheuristics address this issue by using group characteristics, such as average or standard deviation, which take into account the relative values of the heuristics. However, as we have shown, these group characteristics do not adequately measure the similarity of the sets.

Recent MIP approaches measure similarity between sets using the entire histogram, i.e. they measure based on the difference $|\eta_{B_1 c} - \eta_{B_2 c}|$ for each c. Whilst this provides a richer measure of similarity than simple averages, it does not take into account the relationships between attribute values. To return to the word length illustration, the length count vectors $(0, 3, 3, 3, 6)$ and $(3, 4, 5, 0, 3)$ are "equally" different from $(3, 3, 3, 3, 3)$ component-wise. But it is common sense that words of length 2 or 3 are more similar to words of length 4 than words of length 1 are to words of length 5, so the vector $(0, 3, 3, 3, 6)$ "replacing" three words of length 1 with three of length 5 is less similar to $(3, 3, 3, 3, 3)$ than is $(3, 4, 5, 0, 3)$, which "replaces" three words of length 4 with two of length 3 and one of length 2. The component-wise histogram measure does not take into account similarities and differences *between* attribute values.

This paper briefly reviews the existing approaches to automate picking items for experimental sets, and then discusses new MIP approaches that address the entire distribution of attribute values across sets while also taking into account the relationships between attribute values. Numerical results on psycholinguistic data sets are analysed, and the alternative approaches compared.

Keywords: *Mixed integer programming, Stimulus selection, Factorial designs, Experimental psychology*

Time Aggregation for Network Design to Meet Time-Constrained Demand

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Abstract:

We study a network design problem inspired by a strategic planning problem encountered in the Hunter Valley Coal Chain. Demand is given in the form of freight that is available from a specific date and has to be transported from multiple origins to a single destination before its deadline. It is possible to temporarily store freight at certain intermediate locations along the way from origins to destination. The objective is to determine minimum-cost capacity expansions required on the links and nodes of the network, if any, so as to be able to transport all freight within its given time windows.

A natural mixed integer programming formulation with a daily granularity quickly becomes computationally intractable. We investigate the potential of time aggregation to overcome the computational challenges. By aggregating consecutive time periods, a smaller instance is obtained, which can be solved more easily and provides a lower bound on the optimal value.

A carefully designed iterative disaggregation scheme identifies a time aggregation that yields an optimal solution to the original problem. An extensive computational study demonstrates the efficacy of the proposed approach.

Keywords: *Network design problem, integer programming, time indexed models, time aggregation*

A Variable Sized Bucket Indexed Formulation for Nonpreemptive Single Machine Scheduling Problems

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Abstract: The single machine scheduling problem (SMSP) is a classic problem in optimisation which has been extensively studied over the past 60 years. To solve an instance of the problem a set of jobs must be scheduled on a single machine, so that at any time the machine is either idle or processing exactly one job. We consider a nonpreemptive version of this problem which requires that the processing of a job continue uninterrupted for the duration of its processing time. Several mixed integer linear programs exist for the SMSP, with the classic time indexed (TI) model being the most common formulation. The TI formulation can be applied to a range of SMSP variations, with all standard min-sum scheduling criteria capable of being expressed as linear functions of the TI variables. Many complex production planning problems are modelled using TI variables, and so the TI formulation often serves as natural basis for designing mixed integer linear programs to solve these problems. To formulate the TI model the problem data is assumed to be integer and a sufficiently large planning horizon is discretised into time periods of unit length. The length of the planning horizon can be no smaller than the sum of all processing times, and hence grows pseudopolynomially with the size of the problem input. The TI formulation is known to have a strong linear relaxation compared to alternative formulations, however for instances where the sum of processing times is large the resulting model may be intractable due to the large number of constraints and variables.

The authors recently proposed a mixed integer linear program, named the bucket indexed (BI) formulation, for which the time horizon is discretised into periods of the same length and no larger than the processing time of the shortest job. The BI model generalises the TI model to one in which either at most two or three jobs can be processing in each period. In this paper we present a model, named the variable sized bucket indexed (BI-VAR) formulation, in which the lengths of the periods are not required to be identical. This model generalises the BI model to one in which each period is characterised as either permitting at most two, three, or an arbitrary number of jobs to be processed within it. In addition we present necessary conditions for a partition of the time horizon to be valid for the BI-VAR model.

Keywords: *Single machine scheduling, mixed integer linear programming, time indexed formulations*

Directed Voronoi Search: a method for bound constrained global optimization

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Abstract: Global optimization problems occur in many fields including mathematics, computer science, engineering, and economics. The purpose of a global optimization algorithm is to efficiently find an objective function's global minimum, usually in some bounded region. In this article we consider bound constrained global optimization, where the search is performed in a box. The global optimization problem is deceptively simple and it is usually difficult to find the global minimum on general functions. One of the difficulties is that there is often no way to verify that a local minimum is indeed a global minimum. If the objective function is convex, for example, the local minimum is also the global minimum. However, many optimization problems are not convex. Of particular interest in this article are objective functions that lack any special properties such as continuity, smoothness, or a Lipschitz constant.

This article presents a new algorithm for bound constrained global optimization, called Directed Voronoi Search (DVS). At each iteration the objective function is evaluated at a batch of points selected from the optimization region Ω. Initially, the points are selected from a uniform distribution over Ω. These points form a set called the training data and are used to construct a Voronoi diagram on Ω. The Voronoi diagram partitions Ω into a collection of convex polyhedral sub-regions with one point in each sub-region. The objective function is then evaluated at vertices determined by sub-regions containing points with low function values, and large sub-regions. The former direct the search to areas where the objective function is presumed to be low, and the latter shrink large sub-regions to reduce the risk of missing the global minimum. These new points are then added to the training data, the Voronoi diagram is recalculated, and the method repeats.

In order to establish convergence we require that the objective function is lower semi-continuous and bounded below. With these relatively mild conditions the DVS algorithm is shown to converge to an essential global minimizer almost surely. It is also possible to implement a deterministic DVS algorithm. The deterministic instance is shown to converge to an open set essential global minimizer.

Numerical results show that the DVS algorithm is effective at solving low dimensional global optimization problems. Comparisons with the DIRECT algorithm and Accelerated Random Search (ARS) are also made. The DVS algorithm is superior to ARS on the test problems considered and performed similarly to DIRECT.

Keywords: *DIRECT, global optimization, Halton sequence, numerical results, Voronoi diagram*

On the Justifiability of Decision Support Analysis

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Abstract: A decision support analyst's main concern is to understand the problem and its solution space. A decision maker, on the other hand, can have many interests including generating political support, balancing agendas of stakeholders, achieving personal gain, doing the right thing, and so on. It is therefore unlikely that decision maker and analyst have the same view of what qualities the outputs of decision support analysis should exhibit. It is even less likely that they agree on quality borderlines: what constitutes good decision support is ambiguous at best. This ambiguity is exacerbated by the multi-objectivity of decisions making. Potential courses of action cannot be sorted according to an impartial notion of "goodness". As it is the decision maker who "has the problem", it is he or she who usually sets the problem boundaries. Consequently, the decision maker exacts constraints on the decision support analysis and influences its assumptions. In the absence of an unbiased measure for decision quality, both the selection of decision objectives and the definition of problem dimensions are affected by the decision maker's preferences, and so are answers to questions like: where should the emphasis of analysis effort lie, who needs to be consulted for their expertise, and what are the criteria by which to decide what constitutes a constraint and what a variable?

Given the decision maker's interweavement in the analysis, a decision support analysis methodology that wants to ensure justifiability of its outputs cannot be based on the assumption that all those who influence the analysis form a homogeneous group and subscribe to the same set of knowledge generation principles. It cannot assume that decision maker and analyst agree on the arbitration, meaning, sources, and standards of justification. Humans are both the executers of the reasoning that connects decision analysis statements and the owners if not creators of the rules that stipulate how beliefs are transformed to knowledge. Humans determine the criteria by which to judge the "goodness" of the outputs, decide on the appropriateness of methods used in support of decision making, and set the objectives, constraints and assumptions of the decision situation. This human-centricity is not the result of a philosophical position but a consequence of the multi-objectivity of the decision problem. It means that decision maker and analyst "contaminate" any decision support analysis methodology with their worldviews, their preferences, their values, their beliefs and other subjective drivers. It also means that decision support analysis is *dynamic* because decision maker and analyst continuously learn and *open* because decision maker and analyst have interactions with the world that lies outside the boundaries of the decision situation.

These observations lead to several insights of relevance to the construction of decision support analysis methodology. Firstly, a decision support analysis methodology needs to make explicit what is accepted as "truth", what sources of justification are included in and excluded from the methodology, and what standards are to be used in the arbitration process. These decisions are matters of scale. They are directly correlated with the degree of certainty decision support analysts want to have about the effectiveness of their choice of justification source and arbitration principles. Secondly, the choice of sources and arbitration of justification can neither be right nor wrong. It just is. However, the quality of methodology is improved if the analysts' judgments on these matters are made transparent. What kind of judgment is acceptable depends on context and is a question of standards and not of ontology. Thirdly, standards are choices and choices can change. The normative process of methodology formation therefore needs to be continuous and adaptive. A theory that was unknown or irrelevant in 1950 may be something on which most analysts agree today (e.g. hypotheses about cognitive biases). Thus, there is no methodology with eternal applicability. All methodologies are transients. Fourthly, decisions on standards need to be made by somebody and questions arise about the governance of methodology. Currently the individual analyst is possibly the most important authority. He or she is prejudiced by the practices of the disciplines in which he or she was trained. This leads to a medley of opinions in the community of decision support analysts and serves neither this community nor any decision maker particularly well. Finally, epistemology of methodology and axiology of methodology are impossible to separate. The best the authority that decides on arbitration, meaning, sources and standards of justification can do is to be open and honest with respect to the axiological premises of its "theoretical" basis. For example, discussions about whether qualitative research methods are "in" or "out" cannot be resolved by rational argument but merely by admission of faith.

Keywords: *Decision support analysis, multi-objectivity, justifiability, arbitration of justification, standards*

EXTENDED ABSTRACT ONLY

Investigating Parallel Implementations of CP-Beam-ACO

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Abstract: Hybrid methods for combinatorial optimization problems have become increasingly popular. In particular, integrations of exact and in- complete methods have proved to be effective where the hybrid method takes advantage of the relative performance of each individual method. Despite this, these methods often require significant run-times to determine good feasible solutions.

We investigate parallel implementations (parallelization over several cores) of CP-Beam-ACO, a hybrid combining constraint programming (CP) with Beam search and ant colony optimization (ACO). The solution construction of ACO is replaced by a probabilistic Beam search, and unlike ACO, the solution components are dependent on each other. Furthermore, there are increased complexities with calls to a CP solver whereby the selection of components could take significantly different times. Thus, we examine how best the solution construction could be parallelized by investigating parallel implementations on three different case studies.

Our results show that significant speed-ups can be obtained by parallelizing CP-Beam-ACO on several cores. Depending on the level of parallelization, we find minor differences in utilization of the parallel schemes. Not surprisingly, we see significant overheads for those problems with complex CP models.

Keywords: *Constraint Programming, Beam search, Ant Colony Optimization, Multi-core, Car Sequencing, Single Machine Job Scheduling, Resource-constrained Job Scheduling*

A Structured Approach to Extract Strategic Objective Categories from Textual Sources

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Abstract: This paper employs a structured approach to extract strategic decision maker objectives from textual sources as part of a problem structuring activity for constructing decision-aiding models based on historical decisions. It focuses on textual sources as access to original decision makers cannot be guaranteed. The approach combines multiple methods to first identify a comprehensive set of possible decision maker objectives for historical decisions and then map them to a smaller and more manageable set of objective categories. The usefulness and consistency of these objective categories is tested by applying them to an analysis of Australian post-cold war strategic decisions regarding the employment of military force. These objective categories provide an auditable and useful means to structure interviews with decision makers that will inform the modelling process. Objectives were first identified in primary source texts using a method based on directed content analysis (DCA). These objectives were then vetted for possible redundancy using a similarity measure based on Euclidean distance. Next these objectives were structured using *value focused thinking* into a manageable set of objective categories. Finally, the usefulness and consistency of these objective categories was assessed by comparing analyses using these categories of two Australian strategic decisions using two data sources.

This initial problem structuring activity builds on a previous analysis of strategic decisions on East Timor during 1999 (Coutts, 2010) and will be followed by more detailed studies that will include interviews that lead to detailed modelling of the objectives, influences and reasoning behind these decisions. Such decisions are studied by analysts in order to understand the implications of different strategies, improve strategic models and thus better inform future decisions (Auerswald, 2004; Fredrickson and Mitchell, 1984). Employing a structured approach to study these decisions will complement existing research conducted through the political science and international relations disciplines through the concept of methodological triangulation (Webb et al., 1966).

However, challenges exist in structuring a study of historical strategic decisions. When structuring a current decision support problem, analysts can rely on reasonable access to stakeholders and/or decision makers due to the perceived immediacy of the benefits of participation. However such access is often more constrained for historical decisions where there is no immediate pressure on the decision maker to participate and instead the analytical challenge is to structure the study through other means. Of particular concern is the need to structure, and provide rigour to, the design of rare interviews with busy strategic decision makers. Hence the intent of this paper is to produce a manageable and defendable set of objective categories to inform interview design.

***Keywords**:* *Euclidean distance, Value Focused Thinking, problem structuring, historical decision analysis*

Toward a Systematic Process for Science and Technology Foresight

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Abstract: Science and technology (S&T) foresight uses a range of methods, tools and techniques to develop multiple futures on how science and technology may develop in the long-term (20-30 years). These futures are then used to explore the Defence impact and prevent strategic surprise. One problem that is faced by many Defence organisations is how to provide a comprehensive S&T foresight capability when large amounts of resources (money, time and people) are traditionally needed. One solution to this problem is to pool together S&T information from allied nations and contextualize that information to the requirements of specific countries. In June 2011 several allied nations agreed to coordinate their actions under the Technology Coordination Panel agreement. In response to this Action Group 17 (AG-17) Emerging and Disruptive Technologies Action Group was formed. In the following paragraphs and in the presentation we will outline the goals and results of the AG-17 program of work and show how that was developed to provide an initial systematic process for S&T foresight that is being used by the Joint Innovation Centre (JIC), Defence Science and Technology Organisation (DSTO).

The goal of the AG-17 is to *"leverage shared capabilities to mitigate against technology surprise"*. Each of the member nations have different but complementary national requirements and approach the analysis and reporting of emerging and disruptive technology in different ways. The challenge for the AG-17 group was to derive a common analysis and reporting framework. After analysing each of the four approaches to conducting S&T foresight the AG-17 group identified a framework of four common foresight activity categories. Using these categories (described later) the AG-17 members can share (leverage) information on emerging and disruptive technologies from each other.

In late 2012 the JIC was formally stood up with a mission to *"Incorporate scientific, intelligence, academic, industry and international inputs to anticipate areas of threat and opportunities resulting from the emerging technological landscape to create and prevent strategic surprise"*. Two main pillars for supporting this mission were identified. The first, is an organisational structure that facilitates collaboration between DSTO divisions, the wider Australian Defence Organisation, academia and industry. Although this is an important aspect it is not the main focus of this paper and presentation. The second, the focus of this paper, is the development of a strong foresight methodology. Building on the work of AG-17, and previous DSTO experiences, the JIC developed the four step overarching foresight methodology. The main characteristics of the methodology include the integration of the four AG-17 foresight activity categories and the incorporation of underpinning research tasks. The four categories are: 1) Identification, 2) Assessment, 3) Contextualization, and 4) Reporting and Intervention. The methodology has several important advantages. First, it links together each of the four categories of foresight activity in a way that is systematic (logical, organized and efficient). Second, the outputs of the activities and the integration of all the activities meet the requirements of good scientific method (e.g. rigorous, adaptable, objective and auditable). Third, the methodology is suited to consider a longer term view of S&T and their impacts. Fourth, the method supports different levels of analysis (e.g. "quick-looks" and "deep dives"). Fifth, the methodology supports an iterative analysis. Finally, the methodology is based on the output of TTCP AG-17 and so facilitates the exchange of information using a common international "language".

To date the JIC has contributed to the understanding of several important emerging technologies, for example, cognitive modeling, quantum computing, power systems and biotechnology. This has been achieved by leveraging the work from AG-17, having a good organizational structure and through the development of a comprehensive foresight methodology. Over the next few years the JIC science and technology foresight methodology will continue to evolve and support a comprehensive DSTO foresight capability in the face of competing resource demands.

Keywords: *emerging technologies, foresight, disruptive technologies*

Multi-Supplier and Single Retailer Contracts: Profit Splits under Equilibrium

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Abstract: We study contracts between suppliers with fixed capacities and a single retailer with access to customers' demand and the power to influence the purchases of customers. This results in horizontal competition between suppliers and vertical competition between the retailer and his suppliers. The suppliers present the retailer with contracts and the retailer decides how much capacity to buy from the suppliers and sell to the market to optimize his net profits from retail selling. We are interested in the effect of equilibrium contracts on supply chain profit and how profits are split between the suppliers and the retailer.

We assume that the products are substitutable, and there is an inverse demand function so the retailer can control sales through prices. We assume that the retailer can influence the decisions of customers. As products become closer substitutes, customers become more indifferent to the supplier, making the retailer's role more important in deciding which product to offer to customers. We use game theory to analyze the players' interactions and the resulting equilibria on the basis of the players' sets of strategies. We present the results in the Nash framework, where suppliers make their decisions simultaneously, without knowledge of other suppliers' decisions. The game is between suppliers, but must take into account how the retailer will react in response to the contracts. We assume that suppliers' capacities are exogenously determined and fixed. The fixed capacities may be a result from competition at a higher strategic level, and are considered fixed during the contract designing. We also consider a deterministic demand model to focus on the profit split among the players in equilibrium.

Under mild assumptions on the supply chain's profit as a function of aggregate capacity, we show that all equilibria result in a coordinated chain with a unique profit split. The profit of each supplier is equal to the marginal contribution of her capacity to supply chain profits.

Keywords: *supply chain management, game theory, Nash equilibrium, negotiation*

Modelling of Stakeholder Participation in the Centre for Food Innovation

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Abstract: The Centre for Food Innovation (CFI), established in 2013, comprises a partnership of Defence Science and Technology Organisation (DSTO), Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the University of Tasmania (UTAS). The purpose of the CFI is to provide a regional focus for research, education and training in support of the northern Tasmanian food industry. DSTO, CSIRO and UTAS have different institutional charters, strategies and internal operational processes. The partners' individual objectives for requirements of the CFI will need to be accommodated in any decision-making models. In addition, there is a plethora of other potential stakeholders: primary producers, small to medium enterprise (SMEs) processors, industry groups, and Federal, State and local Governments. The development of governance, industry engagement mechanisms, and the building and prioritisation of a research portfolio will require input from and consideration of this broad stakeholder community.

We have used the techniques of 'Soft' operations research to guide the establishment of the process and engagement model. This is classic problem structuring, where the route to achieving an agreed way forward is as important as, if not more than, the resulting outputs: selection and prioritisation of research projects, funding mechanisms, or location of facilities. These output decisions are not logically deducible, for instance the three aspects of research, education and training providing different emphases, while the stakeholder community will impart their specific beliefs and desires. Significant features of a successful planning process include shared understanding, mutual appreciation of interests, joint commitment and visible communication channels all leading to establishment of the sound stakeholder engagement process.

The purpose of this study is to share stakeholder perspectives in order to identify commonalities and differences in their goals, objectives and understanding of the CFI, and then move towrds a common shared vision for the collaboration. Soft Systems Methodology (SSM) provides an auditable, credible and transparent way to undertake this task. Stakeholders will have greater buy-in of and commitment to the common vision, if they believe that the appropriate first steps have been made in a reasonable and sound manner. SSM uses the concept of a 'system' as an interrogative device that enables debate amongst concerned parties who learn their way from finding out about the situation to taking action to support it. SSM is grounded in theory, has a well detailed methodology, and generates models. The models are an ideal way to share stakeholder perspectives and to understand the effects and interactions of the many complex systems that make-up this problem space.

This paper decribes the learnings and insights from the initial phase of this SSM study. We undertook an action research process of developing initial models from each of the key stakeholders perspectives. Facilitated workshops, distributed due to geographical issues, were then held with individual stakeholders to gather feedback and adjust the models accordingly. A final model was then developed to accommodate a shared stakeholder perspective. SSM provided an excellent framework to explore perspectives and identify differences amongst the CFI stakeholders. An activity model was developed which provides an initial shared perspective or 'common' model for the key stakeholders. This 'common' model could then be used as the basis for a workshop to discuss goals and perspectives of the CFI, or used by key decision makers to establish CFI structure, processes and procedures which attempt to factor in this shared common vision. This would better position the CFI to establish organisational structures and processes that better enable a successful future.

Keywords: *Problem structuring, soft systems methodology*

Factors affecting seaport capacity: Managerial implications for a simulation framework

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Abstract: A seaport is a key part of a supply chain. However the problem of system-wide capacity shortage puts seaport authorities under pressure to keep up to date with ways in which to solve it. The purpose of this study is to propose a System Dynamics (SD) framework for managerial decision making that is developed based on the factors affecting seaport capacity. Hence the proposed capacity management framework inherits the potential for use at ports in capacity-management-related problem solving. The framework would be of importance in assisting managers in identifying possible capacity expansion opportunities. Academics and those with corporate interests in the capacity management of ports have raised many issues in recent years in which there has been steady growth in the number of containers transported worldwide.

Keywords: *Simulation, System Dynamics (SD), container terminal, capacity management, port*

Operations Research (OR) at ports: An update

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Abstract: Decision makers today face the problem of exploring ways to increase port capacity. The determination to increase port capacity is influenced by continuous growth in the number of containers entering or departing the port, the constant increase in ship size, as well as by many other, previously unforeseen, factors. Therefore, particularly in recent years, in a time of economic recession, practitioners, as well as academics, have become interested in capacity management. In order to make further contributions to this maritime logistics domain, this paper explores and addresses the drawbacks in the typical sub-system based literature that is available in regard to the subject of port capacity (i.e., literature focusing on specific components of a seaport): this paper also examines studies that could potentially address, diversify and broaden the research pertaining to port capacity expansion. Therefore, the paper presents an extensive review of the Operations Research (OR) literature, including a trend analysis. The trend examination is based on: the year of publication of the literature reviewed, the component or dimension (e.g., problems pertaining to crane allocation) examined, the coverage area (e.g., single or multiple sections) of the port system studied and the specific research approaches (e.g., simulation or analytical) adopted in those studies.

Keywords: *Simulation, Operations Research (OR), container terminal, capacity management, port*

Development of Future Space Concept Options Using Creative Thinking Techniques in Workshops

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Abstract: The Joint Operations Division (JOD) has been using a Concept Option Development (COD) process in order to provide early systems and technology options for Defence to consider in the Needs Phase of capability development. The COD process was presented at the Systems Engineering and Test & Evaluation conference 2010 by the author. COD is used to assess the upgradeability and flexibility of our force structure design in order to influence capability decisions.

This paper discusses the approach and the methods employed to insert concept options in the needs phase for space capability. JOD has provided science & technology support to the development of ADF Space operations since 2008, thus providing a starting point for the Future Space Concept (FSC study). In the FSC study, the COD process has been applied in a different context with groups of Space Subject Matter Experts (SME), brought together specifically for a workshop event to develop FSC options.

The COD methodology aspires to promote insertion of novel concepts to meet potential gaps through the use of creativity and conceptual design. The creative approach adopted in the COD process contrasts with the incremental improvement approach typical of capability development, in which improvements to operational capability are made by applying analytical thinking skills to identify evolutionary performance gains using existing types of systems solutions. The COD process informs the development of space capability through the insertion of concept options and assessment of how these might be integrated in a future context. Early capability option advice allows the customer / operator communities to assimilate possibilities, different avenues and opportunities available to meet capability gaps or to improve military capability.

Two workshop case studies are described. Creative thinking techniques were used, in conjunction with drawing from the considerable depth of expert knowledge available at the events. The lessons learnt and the types of results gained from using creativity and conceptual design with groups of SMEs are presented and discussed. The case studies provide insight into how a group of highly experienced SMEs can be brought together to perform innovation in a small amount of time and in a structured format.

Keywords: *Innovation, Conceptual design, Early technology insertion, Applied creative thinking techniques*

Mathematical Programming Gives Hard Bounds of the Dirichlet Problem for Partial Differential Equations

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Abstract: Differential equations, either deterministic or stochastic, play an indispensable role in modeling virtually every dynamics in physical and social sciences and devising efficient computational methods for differential equations is thus of paramount importance out of sheer necessity. The existing methods, such as finite difference, finite element and spectral methods, are designed to provide a good approximation of the solution, while approximation results do not provide any direct information about where and how far the true value is. We propose a novel numerical method based on mathematical programming for the Dirichlet problem for elliptic and parabolic partial differential equations without discretization. Our method is designed to provide hard upper and lower bounds of the solution by mathematical programming. The availability of hard bounds is of paramount significance as those hard bounds form a 100%-confidence interval in the context of probabilistic Monte Carlo methods. An optimization problem is formulated based upon the probabilistic representation of the solution and can be solved by semidefinite programming with the help of sum-of-square relaxation. Various theory-based techniques are developed to cope with difficult situations, such as finding a bounding polynomial function over the entire domain through a single implementation of the optimization problem. Numerical results are presented to support our theoretical developments and to illustrate the effectiveness of our methodology and techniques.

Keywords: *Elliptic partial differential equation, parabolic partial differential equation, polynomial program-ming, semidefinite programming, stochastic differential equation, sum-of-squares relaxation*

INVITED TALK

EXTENDED ABSTRACT ONLY

OA and OR – time for a divorce – or at least some time apart

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Abstract: In a seminal article in the Journal of the Operational Research Society (Feb 1979) Russell L Ackoff pronounced dead the discipline of Operations Research. His arguments for doing so were as follows:

'By the mid 1960's most OR courses in American universities were given by academics who had never practised it. They and their students were text-book products engaging in impure research couched in the language, but not the reality, of the real world. The meetings and journals of the relevant professional societies, like classrooms, were filled with abstractions from an imagined reality. As a result OR came to be identified with the use of mathematical models and algorithms rather than the ability to formulate management problems, solve them, and implement and maintain their solutions in turbulent environments..... This obsession with techniques, combined with unawareness of or indifference to the changing demands being made of managers, had three major effects on the practice of OR.

- *First, practitioners decreasingly took problematic situations as they came, but increasingly sought, selected, and distorted them so that favoured techniques could be applied to them. This reduced the usefulness of OR*
- *A second effect of the technical perversion of OR derived from the fact that its mathematical techniques can easily be taught by those who do not know where, when and how to use them. This, together with the fact that in the late 1960s use of quantitative methods became an "idea in good currency", resulted in these techniques being taught widely in schools of business, engineering and public administration, among others. This has deprived OR of its unique incompetence; an increasing portion of it is done by those who do not identify with the profession. ... What this dispersion signifies is that OR has been equated by managers to mathematical masturbation and to the absence of any substantive knowledge or understanding of organizations, institutions or their management.*
- *Thirdly, 'in the first two decades of OR, its nature was dictated by the nature of the problematic situations it faced. Now the nature of the situations it faces is dictated by the techniques it has at its command. The nature of the problems facing managers has changed significantly over the last three decades, but OR has not. It has not been responsive to the changing needs of management brought about, to a large extent, by radical changes taking place in the environment in which it is practised. While managers were turning outward, OR was turning inward inbreeding and introverting. It now appears to have attained the limit of introversion: a catatonic state.'*

Then nothing happened, or rather, a lot did: these trends continued and accelerated. OR is now everywhere and is increasingly specialised: econometrics, finance, analytics, supply chains, reliability, safety, climate... – the list goes on. Many of the practitioners do not see themselves as operations researchers but as economists etc. To establish their importance to their employers OR practitioners have had to narrow the range of problems with which they deal and specialise in a narrow range of directly applicable techniques.

In the meantime, life in the real world moved on. In the field of military OR the nature of the problem grew in complexity and the need for systems perspectives grew. In response to needs such as this the notion of soft OA emerged in the mid-1990s but it was but it was not until 2012 that NATO produced doctrine on Soft OA stating that "approaches (i.e. theories, methods, techniques, models) within Operational Analysis (OA) that are predominantly based on human judgement, are an increasingly critical capability needed to support defence decision making. Judgement in different guises has been used by military staff whenever assessing problematic situations and making decisions. The field of judgement-based methodologies and methods within OA is usually known as 'soft' OA. It has a significantly more qualitative and subjective nature than the traditional, 'hard', OA methodologies which tend to be significantly more quantitative and objective."

The term 'soft OA' is something of a cop-out and, in Ackoff's terms, represents a further 'dispersion' of the discipline. The paper goes on to pose the argument that it is time to separate pedagogy and practice into OR - that deals with mathematical techniques used to model and analyse defined problems – and OA which focuses on the support of decision makers and is therefore primarily concerned with problem structuring, methodological development, sense-making from results and visualisation. In this construct OA uses OR techniques but extends well beyond them. If this model were to be adopted the essential interdisciplinary nature of OA and its focus on the needs of decision makers might be re-established and it might subsequently regain its position as a discipline in its own right.

***Keywords**:* *Operations Research, Operations Analysis, Problem Structuring*

Toward new combinatorial structures using a roundabout model with security related applications

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"When the fact encountered does not concur with an accepted theory, one must accept the fact and abandon the theory" (translation). **Claude Bernard.** (1813-1878)

Abstract: This modeling-oriented research focuses on the "physical look" of combinatorics output. It is a well known, simple triviality that for combinations with repetitions of n elements taken k = 2 elements at a time, the output contains only items where the exhaustive meetings property prevails. The questions automatically arises as to how to exploit this promising property in the technological field of operations research, and how to modelize and generalize items to algorithmically obtain outputs with the exhaustive meetings property. We believe that our work will find answers to these conceptual questions.

Let k be any positive integer representing the k rows of a matrix having n columns chosen as a function of k such that n = k (k-1)+ 1. It is possible to rotate each row of the matrix to satisfy the following strong constraint: in the distribution of k-tuple column-vectors obtained by rotations, elements of the matrix meet others once and only once in each column, taking into account the simultaneous presence of k to k elements in the columns. While it is true that the above constraint is concordant with the Golomb Ruler referring to a set of non-negative integers such that no two pairs of distinct numbers from the set have the same difference, this same strong constraint does not limit us solely to finding a shorter Golomb Ruler in order to be able to open the horizon towards new and broader fields of application such as the manufacturing of high security spherical locks and promising encryption-decryption processes, for example. In addition to these potential applications, I will also present my pseudo-genetic roundabout algorithm, and a more in-depth theoretical overview.

Keywords: *pseudo-genetic algorithm, exhaustive meetings property, k amplitude Hamiltonian matrix, contraction, dilatation*

Contextual Clustering
Grouping and classifying problems in a defined context

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Abstract: Contextual Clustering is a new Operations Research technique designed to objectively group issues within a defined context. It does not rely solely on subject matter expert opinion and provides an audit trail and logical path to the final results. Contextual Clustering enables analysts and decision makers to gain a better understanding of the problem space by considering it as a whole and then defining themes for further investigation whilst removing pre-conceived ideas and biases.

There were three key drivers in its development the most important being the need to construct a defined context for all participants to ensure that responses are based on the specified (new) concept. This should encourage participants to think beyond current practices and assist them to break current day paradigms. The next was the desire for a quick turn around time (approximately one to two hours) with limited resources, to enable feedback and further discussion with participants based on the findings during the same activity or workshop. The final key driver was the need to conduct an objective and rigorous analysis that would provide a firm basis for any future investigations. In addition to these drivers the following constraints were applicable; a small sample size (limited number of participants), a large quantity of complex inter-related issues for consideration, the unavailability of training data and the desire to conduct additional sensitivity analysis. As a result the Contextual Clustering technique was created with inspiration from a number of techniques and could be described as a "meta-method" or flexible Operational Research approach that enables the use of the most appropriate algorithms and techniques as required. The basic steps of Contextual Clustering are: (1) determine the characteristics that define the context; (2) identify issues for clustering; (3) capture relationship data; (4) apply appropriate clustering algorithm; (5) graphically represent the clusters to apply labels and enable discussion; and (6) validation/confirmation of clusters.

Contextual Clustering should be considered when conducting analysis of issues related to new concepts or contexts where an objective and rigorous analysis is required. It allows analysts and decision makers to gain a better understanding of the problem space by considering it as a whole and then defining major areas for further investigation. As a result Contextual Clustering is an especially useful technique during the problem definition and scoping stages of larger problems, as it groups issues into themes enabling a range of issues to be studied simultaneously rather than individually. The main aim of Contextual Clustering is to ensure that participants consider issues within the specified context, removing pre-conceived ideas and biases compelling participants to think about the problem differently and thus enabling current day paradigms to be broken. However, it should be implemented as part of an overarching schema including group discussion or the application of a subjective method. This will confirm immediate results and in the long term, help to validate the Contextual Clustering technique as a process for exploration of new concepts or contexts.

Keywords: *Grouping, classification, context; category; operations research; operational analysis*

Modelling the Uptake of Energy Efficient Technologies in the Residential Sector

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Abstract: The growing demand from government planners and policy makers has led to the development of specialised decision support tools to assist in evaluating the myriad of options, policies, strategies and programs aimed at reducing energy consumption and the associated greenhouse gas emissions in every sector of the economy. The residential sector continues to be a major focus for sustainability and reduction efforts in Australia with its significant share of energy consumption. This paper presents the basic capabilities of a decision support tool aimed at creating future scenario projections based on known population and housing trends in NSW initially, and applied to other Australian states eventually. Codenamed TERENCE (Tool for the Evaluation of Residential ENergy Consumption and Emissions), the tool allows planners, researchers and policy makers to assess the relative impact of assumptions about future technology and policy using a defined baseline (or "business as usual" scenario) for comparison. TERENCE combines a highly graphical and visual presentation with geographical granularity only limited by the availability of data. This paper describes the application of TERENCE in evaluating different rebate scenarios aimed at estimating the uptake of various water heater options by 2030.

Keywords: *Energy modeling, simulation modelling, technology diffusion, multicriteria analysis*

Decentralised Resource Scheduling with Confidentiality Protection

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Abstract: As resources become scarce and expensive, it has become increasingly important for players in a decentralised supply chain to cooperate and share the scarce resources. Several studies have shown that lack of coordination can result in a poor performance in terms of cost and efficiency of the supply chain.

A collaborative supply chain means that two or more independent players work jointly towards a common goal to execute supply chain operations with greater success than when acting in isolation. However, the players are competing companies and even though they are willing to cooperate to improve efficiency and minimise total cost of the supply chain, they do not wish to reveal confidential information about their jobs. Among others, this would include details of the job, like: first time when a job could be started, amount of time required to process the job, due date and importance of completing the job before the due date. Such information could potentially be used by competitors to attempt to prevent on time delivery, or to attempt to gain a competitive advantage. It is therefore important to develop algorithms which can allow various participants to cooperate without needing to share any private information.

Following recent literature on the topic of coordination in supply chain management, it is usually stated that information sharing is essential for obtaining coordination. In this paper we show that to achieve coordination it is not essential to share any information but only a commitment to collaborate, which is a pre-requisite to sharing any information anyway. Taking a decentralised resource constrained scheduling problem as an example we present in this paper a methodology which can be used to calculate correct lower and upper bounds on the objective functions without needing to share any private data from individual players. Specifically, the problem considered in this paper is motivated by the mining industry in remote off-grid areas where mines are independent players with preassigned mineral processing jobs to be processed on their own machine/mining site. Each job also needs a certain amount of electricity in order to get completed. The electricity, on the other hand, is of limited supply and must be shared between the mines. It is also assumed that all the data is decentralised and mines are not interested in sharing any private information about their jobs. We present a lagrangian relaxation based algorithm which allows us to find correct lower bounds even when the data is decentralised and we also present two heuristics which are shown to converge to Nash's equilibrium. Computational results on comparisons of our heuristics are also presented which demonstrate that our methodology can be used in practice.

Keywords: *Decentralised data, shared resources, collaboration, confidentiality protection, lower and upper bounds.*

The Junior School Class Allocation Problem – A Mathematical Programming Solution

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Abstract: Friendship groups are an important element in both the social and academic well-being of school students, particularly in their younger years. Each year, school management has to assign students to a particular class in their new grade in junior school, and in doing so make and break friendship preferences as other criteria need to be satisfied, for example gender balancing. This ongoing administrative task is time-consuming and does not always result in the most equitable allocation. Coupled with the lack of transparency of the process, this can lead to student/parent frustration.

This paper reports on a case study conducted at the author's sons' school. The study sought mathematical programming approaches to find fast solutions that were both better overall (optimal) and individually (equitable). While the mathematical literature is awash with applications for timetabling problems, the author is unaware of examples for the junior school class allocation problem.

While it is straightforward to articulate in English, the problem is inherently quadratic in nature, and when coupled with integer constraints, the resulting quadratic integer (binary) program is notoriously difficult to solve exactly. Three different formulations were considered, each resulting in a Mixed Integer Linear Program (MILP), but of differing compactness.

To offer a pragmatic approach, only non-commercial solvers (the R package LpSolve and SCIP) or free access to commercial solvers (Gurobi through the Network-Enabled Optimization System (NEOS) server) were considered. The problem of allocating 59 students into 2 classes subject to 3 balancing constraints (size, gender and learning support needs), ensuring a minimum number of friends individually, and maximizing the total number of friend requests was tackled. To avoid seeking sensitive data, learning support needs and student friend requests were estimated.

So, what did I learn from this exercise?

First, it is likely that mathematical programming tools can be of pragmatic assistance to schools in their annual junior class allocation problem, if chosen correctly. Looking at the formulations investigated here, the largest was most prone to not return an optimal solution in any practical amount of time, while the smallest formulation was clearly the best (for this problem at least). That is, it can reduce the amount of 'manual labour' in generating feasible classes and it will likely provide a better, and individually fairer, solution than that manually generated. For a typical-sized problem, a total improvement of around 30% was possible, as well as ensuring at least two friend requests from each student (originally it was thought that only one friend request could be guaranteed).

Second, the quality of solvers can vary enormously and that the motto 'you get what you pay for' may well be accurate. As claimed by their proponents, SCIP is very much faster than LpSolve (here, around an order of magnitude) and Gurobi is much faster than SCIP (here, at least twice as fast). However, non-commercial entities (like schools) can access for free very good MILP solvers - either SCIP as a stand-alone product or Gurobi (or SCIP) via the NEOS Server.

Third, and finally, it should be noted that other features may also be accommodated within this mathematical programming paradigm. This includes other constraints, like *class mixing* to avoid last year's class predominantly becoming this year's class, and using a finer preference measure to delineate *best friends* from other friends as well as *negative friends* to avoid personality or other clashes. An extension to the multiple (>2) class problem (as applies in middle and senior school) also appears feasible.

Keywords: *Junior school, class allocation, mathematical programming, linearisation*

Evaluating Absolute Capacity of the Emergency Department

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Abstract: The function of the Emergency Department (ED) is to provide care for acutely unstable and unwell patients, differentiate patients for medical or surgical admission, and treat non-life threatening conditions requiring immediate attention. Demand for ED services is increasing and hospitals are focused on providing effective patient care with efficient resource management. In this paper we propose an analytical model to determine the absolute capacity of the ED, which is the maximum number of patients that can be treated within a fixed time period. The absolute capacity is an upper bound for effective patient care based on the processing requirements of the patient cohort and the available treatment spaces in the ED. A linear programming formulation combines the processing requirements with patient arrival rates to determine the optimum level of staff and other resources required to maximise efficiency. A case study is used to analyse the approach.

Understanding the efficiency and effectiveness of ED operations is an important part of meeting the increase in demand for ED services. This requires an understanding of the theoretical maximum volume of patients that can be treated within a fixed time period. We introduce an analytic model to compute a theoretical upper bound for ED capacity, this is the absolute capacity. The model takes as input the processing requirements of the patient cohort and the resource availability to determine the absolute capacity.

Each patient arriving at the ED requires some set of treatment tasks and we can distinguish patient types based on similar sets of treatment tasks. A patient cohort is described by the proportional mix of patients across the different types and the treatment tasks required for each type. This, along with the arrival rates, fully characterizes the patient demand.

On the service side, we examine the resource requirements for each treatment task. The resources of the ED can be classified broadly into beds, staff and equipment. A patient requires a bed of a specific type to span the duration of all treatment tasks, then staff and equipment resources for the individual treatment tasks. For example, an X-ray task requires the X-ray machine (equipment resource) and also possibly a nurse (staff resource) to monitor the patient during the X-ray. Each task occupies the resource for a certain duration, for simplicity in this case we assume a deterministic duration.

The linear programming formulation maximises the ED capacity subject to constraints on the proportional mix of patients, demand on treatment resources and percentage occupation of those resources. We compute the absolute capacity on a case study ED with 30 beds, eight patient types, and seven resource groups. This gives the maximum number of patients that can be treated back-to-back on a set of perfectly efficient resources. Comparing the absolute capacity to the current operational capacity of a real ED we get an idea of the *efficiency gap* which is part theoretical and in part an indication of where performance gains can be made.

The mathematical framework links the patient demand to the resource utilisation and outputs the theoretical maximum number of patients that can be treated in the ED. Using this framework, we derive expressions for resource intensity and resource hours per patient. These quantities measure the demand placed on each type of resource by an individual patient. We use the framework for a given set of patients with a random arrivals to compute the minimal set of perfectly efficient resources required to treat the patient cohort. In this case we use the same 30 bed ED with eight patient types and a fluctuating arrival rate resulting in approximately 100 patient arrivals per day. The results give minimal staffing levels required to treat the arriving patients with perfect efficiency.

Keywords: *Emergency department, capacity, optimisation, patient flow.*

Input system for simulation system with Excel

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Abstract: Currently there exists a variety of simulation systems. We have been conducting research on available general-purpose simulation systems that focus on how people queue. For example, the queuing is in a hospital or a supermarket, etc. This research is applicable to various fields, such as medical treatment and management.

With regard to simulation systems, there are requirements within the fields of business, management and information technology. However, owing to the difficulty of using simulation language and interface the difficulty of their use, these systems have not been widely adopted.

Therefore, we have conducted research on simulation systems using spreadsheet software that is already widely in use. Spreadsheet software is installed on many computers along with word processing software. For this reason, many computer users already have a basic understanding of the software. Moreover, new improvements in this software appear year by year, so that as computer performance also improves, if we are able to construct a system, we will be able to carry out simulations more rapidly, as well as use the higher functionality of Excel to perform complex statistical processing and future projections.

We have already proposed a simulation system on Excel called the SIMEX. By introducing an easy to use interface through building a model input using VBA, a program run through Excel, we can achieve a simulation of the type described earlier, using the various numerical functions of Excel.

In this study, in order to make the functions of SIMEX even easier to use, we isolated the model input. In so doing we were able to achieve greater flexibility in the model input function, thus creating a more visually intelligible model along with the results we obtained from our simulation on Excel.

The simulation procedure for this system is as follows:

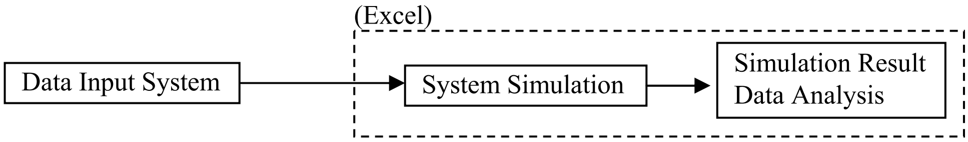

Fig. 1 SIMEX system diagram

It is easier to implement this system than a former similar simulation system. And, after inputting, we will get the result of information on Excel, like "Trace Simulation worksheet" which SIMEX has realized.

In the future we hope to achieve a simulation system in conjunction with spreadsheet that will take advantage of input application developments using smart phones. Even when programs (applications) are run independently, they will be able to share data through a network and run unified simulations. In other words, it is a network-type, object-oriented simulation system.

Keywords: *simulation language, transaction flow-type system, manufacturing system , excel language*

UK initiative for healthcare simulation

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Abstract: In 2006, the UK NHS Institute for Innovation and Improvement conducted a study to determine what tools were being used for strategic planning within the UK NHS. The results indicated a lack of support for organisations looking to analyse the impact of policy changes or changes to their service provisions. As a result of the NHS survey, the SIMUL8 Corporation were approached to develop a tool to support strategic decisions within the NHS. The two organisations collaborated for two years in the development of a new tool called the Scenario Generator.

The vision for Scenario Generator was to develop a tool that could be used by non-technical individuals at any level of the health organisation to help inform decisions. The tool is easy to use with only minor training and customisation required. The tool can be used at a high level to understand the impact of strategic or policy decisions or at the low level for informing operational decisions.

In addition to the English and Scottish NHS the Scenario Generator has now been adopted by health providers in Canada, Italy and the Netherlands and is set to continue to help shape the delivery of healthcare for years to come.

The tool is intended primarily for commissioners, service planners and clinical teams, to help them to:

- understand the consequence of, and to plan effectively for, changes to the way that healthcare will be delivered;
- explore the impact of population growth and migration, changes to demographics and disease prevalence on their existing and future models of service delivery;
- test possible strategic approaches to reconfiguration of services, such as the impact of reducing referral rates into secondary care;
- design and test the performance of proposed changes in clinical practice (e.g. new referral guidelines, care pathways, models of care, high impact changes) on the performance of their local health system.

Scenario generator is novel in a number of ways:

- it is designed to be user configurable (without programming or specialist skills) and applicable to a wide range of planning decisions;
- it is aimed at healthcare analysts, managers and clinicians, not at experts in use of modelling and simulation tools;
- it uses discrete event simulation to model a whole healthcare system;
- it incorporates a suite of configurable pathways of care (a now familiar paradigm in the NHS) to represent the deployment of healthcare services in the system.

This innovation was recognised in 2010 when the Scenario Generator was shortlisted as a finalist in the BT e-health awards competition for "Healthcare IT product innovation".

The presentation will provide an overview of the tool and present a number of case studies where the tool has been used to support for improvement initiatives.

The presentation will also discuss some of the opportunity and challenges experienced in the on-going attempts to implement the tool in Australia.

Keywords: *Health, decision support system, simulation, policy, strategic decision making*

A generic ambulance scheduling and rostering methodology using flow-shop scheduling techniques

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Abstract: Ambulances operate in an environment where demand for services is expected to increase (fuelled by an increase in urgent and life-threatening incidents), however, ambulance services are expensive to run and resources are often limited by cost constraints. Ambulance services also have to deal with the transfer and admittance into hospital of patients arriving by ambulance. The decision to send a patient to a particular hospital is dependent on several factors. These include patient requirements where there exists a preference for taking a patient to a particular hospital, distance to hospital and the current status of the hospital emergency department. Metropolitan areas are densely populated with frequent calls for emergency medical services. In this environment, multiple ambulance stations are able to co-operate to provide coverage. Scheduling decisions are made to allocate ambulance vehicles to ambulance stations, dispatch ambulances to medical emergencies and transfer each patient to an appropriate hospital.

A static flexible flow shop model has been developed as a mixed integer program modeling the process of ambulances responding to calls. The application of flow shop scheduling techniques presented in this model allows the ambulance scheduling problem to be formulated as a single-stage model applying rostering rules as constraints. The inclusion of overtime as a decision variable in the objective is an innovative approach to optimising ambulance schedules and rosters.

Five processes are defined and must be followed in the strict precedence order depicted in Figure 1. This formulation only allows ambulances to be dispatched from static locations (i.e. ambulance stations) and waits for ambulance to finish returning to stations before they can respond to another call. As a result of this assumption, the model is expected to overestimate the total number of ambulances required and thus provides an upper bound on the minimum number of ambulances required in a region.

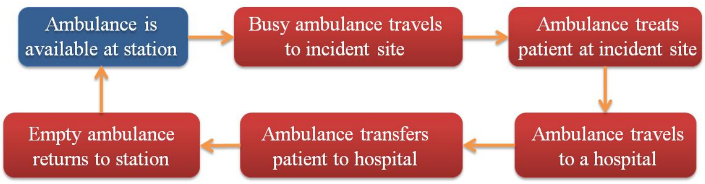

Figure 1: The various stages that an ambulance will pass through when responding to a call.

The objective, shown in Equation 1, minimized the weighted sum of regular rostered work hours in the first term and accrued overtime in the second term across K different types of ambulance vehicles. The decision variable x_{asf} is equal to 1 if ambulance a is rostered to work at ambulance station s during shift f. The number of units of overtime worked by ambulance a at the end of shift f is represented by τ_{af}.

Minimize $$\sum_{k\in K}\left(\omega_k\left(\sum_{a\in A_k}\sum_{s\in S}\sum_{f\in F} x_{asf}\right)+\sigma_k\left(\sum_{a\in A_k}\sum_{f\in F}\tau_{af}\right)\right) \quad (1)$$

Constraints applied included scheduling constraints to enforce precedence of processes, prevent overlapping processes on a single ambulance and to ensure responses were received in appropriate time windows. Constraints were also applied to ensure that the assignment of patients to ambulances and hospitals was appropriate for the needs of the patient. A `dummy' hospital was introduced where no transfer to a hospital was required. Rostering constraints prevented the same ambulance working adjacent shifts or being assigned to a patient during a shift onto which they were not rostered. Ambulances in the middle of responding to a call were able to continue working past the end of their shift but this would cause overtime to be non-zero.

Keywords: *Emergency medical services, ambulance scheduling.*

Short term health impact of air pollution in Europe

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Abstract: Air pollution has a substantial impact on human health. During the last decade, a substantial improvement on air quality modelling has been performed. The last decade scientific studies have indicated an association between air pollution to which people are exposed and wide range of adverse health outcomes. Sophisticated 3D Eulerian numerical models have been developed to be applied to estimate the air pollution concentrations based on the improvement on weather forecasts and the substantial progress on knowledge on atmospheric chemistry. The accuracy on the estimated concentrations at surface level on space and time is currently quite important. We have developed a tool that is based on a model (MM5-CMAQ) (PSU/NCAR and US EPA) running over Europe with 50 km spatial resolution, based on EMEP (European official emission inventory) annual emissions, to produce a short-term forecast of the impact on health.

The system is based on the BENMAP tool developed by EPA (US). The system estimates the mortality change based on the air pollution change, the mortality effect (Beta), the mortality incidence and the exposed population. In order to estimate the mortality change (forecasted for the next 24 hours) we have chosen a log-linear (Poisson) regression form to estimate the concentration-response function. The parameters involved in the C-R function have been estimated based on epidemiological studies, which have been published by the European APHEIS (Air Pollution and Health: A European Information System) program and the WHO (World Health Organization). We have derived the relationship between concentration change and mortality change from the C-R function which is the final health impact function. Since with a 24-hours air pollution forecast of the air concentrations, we have used the European epidemiological studies with different relative risks (RR) to relate them with the daily air forecasted concentrations to obtain a relationship to be applied to all grid cells in the European domain. Since the relationship depends on the forecasted air concentrations, this relationship is calculated daily. In this contribution we show health impact European maps for PM10 daily average and O3 (maximum of the 8-hour moving average) and deaths for all causes, deaths for respiratory and cardiovascular diseases and Hospital admissions for respiratory and cardiovascular diseases. All this calculations are made using a computational scripts developed ad-hoc for the operational system.

Keywords: *Health impact, air pollution, numerical model, relative risk*

An analytical model for the capacity usage of emergency departments

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Abstract: State and local governments had increased health spending by about nine per cent per year for five financial years up to 2009-10. Nevertheless patients are still experiencing long delays in emergency departments (ED), which have little control over the rate of people presented. With limited resources, some patients will have to wait longer for treatment. The Australasian Triage Scale (ATS) is a scale tool for rating clinical urgency (Category 1 to 5). The ATS is also regarded as a key performance indicator for health funding as set out in the National Healthcare Agreement between the Australian Commonwealth and State Governments.

In an ED, Category 1 patients are to be treated immediately in resuscitation rooms. Category 2 patients and 3 patients (recommended waiting time 10 and 30 minutes respectively) are generally treated in the acute beds. Category 4 and 5 patients are less urgent and are generally treated in the sub-acute beds. For resource planning, this paper investigates the number of beds required according to specific performance targets using historic data or data from forecast. The problem is formulated as Mixed Integer Programming Model. The problem is NP-complete and it is solved by meta-heuristics (see Figure 1).

The solution gives the capacity of the ED and also serves as a benchmark. The model has also been applied to investigate different bed assignment policies.

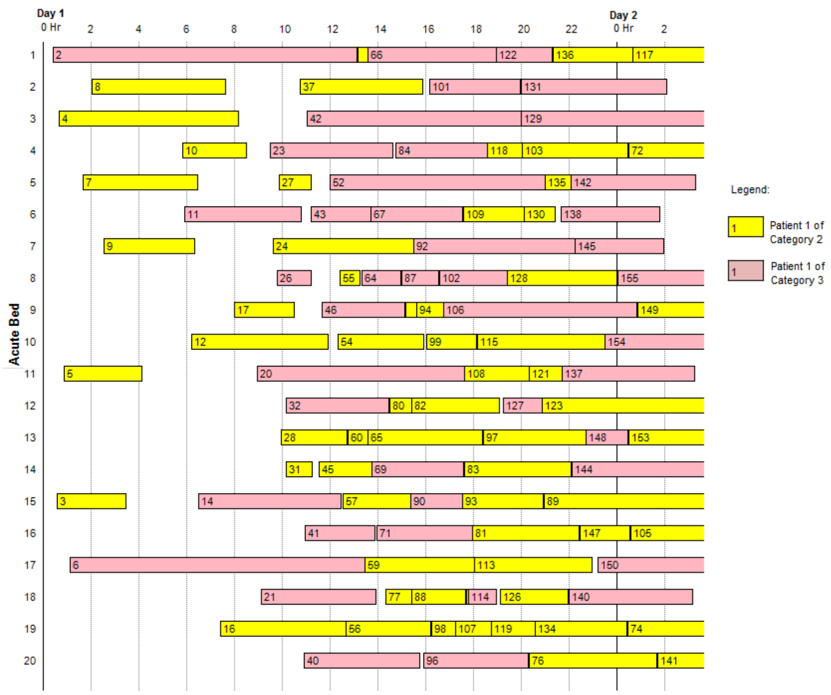

Figure 1. Optimised schedule for Category 2 and 3 patients from real-life sample data

Keywords: *health management, emergency department, patient flow, optimisation, meta-heuristics*

Nomination-based Session Initiation Protocol Service for Mobile Ad Hoc Networks

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Abstract: With the increasingly popularity of mobile devices (e.g. iPhones and iPads), Mobile Ad hoc Networks (MANETs) has emerged as one of the topical research areas in recent years. The special characteristics of MANETs (i.e. infrastructure-less and self-configuring) provide a flexible way of connecting mobile devices. Due to the inherent characteristics of MANETs (e.g. self-configuration of IP addresses), implementing Voice over IP (VoIP) services over MANETs remains an ongoing research challenge. In this paper, we demonstrate how we can adapt the widely used Session Initiation Protocol (SIP) (a signaling protocol used to establish, manage and tear a VoIP session) over MANETs using the Nomination-based mechanism. Our proposed solution employs two security mechanisms to form the underlying model of adapting SIP service over MANETs. We then simulated the setup under different conditions and evaluated the results using various metrics (e.g. Trust Level, Proxy Server (PS) Load, Network Delay, Success Ratio, Network Management Packets, Scalability, and Stability).

Keywords: *Mobile Ad hoc Networks (MANETs), Session Initiation Protocol (SIP), Voice over IP (VoIP)*

Interference-Aware Multipath routing protocols for Mobile Ad hoc Networks

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Abstract: Routing plays a major role in determining the overall throughput and the delivery ratio in mobile networks, and is an area of active research for mobile ad hoc networks (MANets). . This paper presents two routing protocols:(1) Least delay, Interference Aware Multipath Routing protocol (LIMR) and (2) Shortest path, Interference Aware Multipath Routing protocol (SIMR). Both proposed protocols are designed to reduce the influence of interference between the selected node-disjoint multipath schemes, by selecting node-disjoint routes with the minimal interference between them. In both protocols, we use a new technique in order to reduce the control packets overhead, while enabling the destination node of collecting the required information. The main difference between the two proposed routing protocols is the path selection criteria; it mainly affects the Average End-to End delay. LIMR arranges the routes according to their Latency, while SIMR arranges them in ascending order according to the number of hop count.

As in all routing protocols for MANETs, both proposed routing protocols have four main phases, Route Request, Route Reply (RREP), Data relay, and Route maintenance phase. The route request phase is fired by the source node when there is a need to communicate with any destination node with no known routing information. Thus, it broadcasts a route request packet. Each intermediate node is allowed to receive the request packet only from different incoming links. The intermediate node stops receiving the request packets after a certain pre-specified duration of time. In the route reply phase, the destination node is responsible for replying to the first received RREQ packet (least delay route), waiting a specific period of time to collect more routing information, arranging routes in an ascending order according to their path selection criteria, selecting the first route as the main route and finding other disjoint routes set with the main route, adding a flag to the main route, deriving the interference nodes set for each selected route, prior to sending back the RREP packets. Each RREP packet contains the entire route information and the set of addresses for the interfering nodes with that route. In the data relay phase, the source node distributes the traffic load on the main route and the least interfering route with that route. The route maintenance phase is fired when an intermediate node detects a link break. The RERR packet is sent back to the source node, and the source node try to find another route that is considered as the least interfering routes with the main route.

Our simulation results show that LIMR performs better than SIMR in decreasing average End-to-End delay. Results show that the proposed routing protocols have a higher delivery rate and higher throughput compared with the ones in Split multipath routing protocol (SMR). LIMR improves the delivery ratio of the SMR by 37.41 %, while SIMR improves the delivery ratio of the SMR by 32.8 %. LIMR improves the throughput of the SMR by up to 28.1%. The developed routing protocols reduce the average frequency of control packet by 74%.

The significant improvement in packet delivery ratio results mainly from reducing the impact of hidden terminal problem. Increasing the number of available channels between the selected disjoint routes is the main reason for the dramatic improvement in throughput. The efficiency of the proposed protocols and SMR protocol is evaluated by GloMoSim simulator.

Keywords: *MANETs, Interference, Multipath, Routing.*

A branch-and-bound algorithm for scheduling unit processing time arc shutdown jobs to maximize flow through a transshipment node over time

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Abstract: Many real world complex problems can be viewed as networks with arc capacities, for example, rail networks, or supply chains, in which system throughput needs to be maximized. Arcs in such a network represent important components of the corresponding system, the condition of which may degrade over time. Maintenance of these components (arcs of the network) is important to maintain their productivity. But every maintenance activity incurs some loss of productivity as the arc will be unavailable during its maintenance. To obtain maximum throughput, it is important to select the schedule that leads to minimum loss of flow. In this paper we discuss optimization models for scheduling arc maintenance so as to maximize the throughput of the network, and focus on the case in which each maintenance task requires a single period and the network has a single transshipment node. We note that even this case is strongly NP-hard.

Mathematically the problem is defined over a network $N = (V, A, s, t, u)$ with node set V, arc set A, source $s \in V$, sink $t \in V$ and nonnegative integral capacity vector $u = (u_a)_{a \in A}$. We permit parallel arcs, i.e. there may exist more than one arc in A having the same start and end node. By $\delta^-(v)$ and $\delta^+(v)$ we denote the set of incoming and outgoing arcs of node v, respectively. We consider this network over a set of T time periods indexed by the set $[T] := \{1, 2, \dots, T\}$, and our objective is to maximize the total flow from s to t. In addition, we are given a subset $J \subseteq A$ of arcs that have to be shut down for exactly one time period in the time horizon. In other words, there is a set of maintenance jobs, one for each arc in J, each with unit processing time. Our optimization problem is to choose these outage time periods in such a way that the total flow from s to t is maximized. More formally, this can be written as a mixed binary program as follows:

$$P(1) \qquad \max\ z = \sum_{i=1}^{T} \left(\sum_{a \in \delta^+(s)} x_{ai} - \sum_{a \in \delta^-(s)} x_{ai} \right) \tag{1}$$

$$\text{s.t.} \quad x_{ai} \leqslant u_a \qquad a \in A \setminus J,\ i \in [T], \tag{2}$$

$$x_{ai} \leqslant u_a y_{ai} \qquad a \in J,\ i \in [T], \tag{3}$$

$$\sum_{i=1}^{T} y_{ai} = T - 1 \qquad a \in J, \tag{4}$$

$$\sum_{a \in \delta^-(v)} x_{ai} = \sum_{a \in \delta^+(v)} x_{ai} \qquad v \in V \setminus \{s, t\},\ i \in [T], \tag{5}$$

$$x_{ai} \geqslant 0 \qquad a \in A,\ i \in [T], \tag{6}$$

$$y_{ai} \in \{0, 1\} \qquad a \in J,\ i \in [T], \tag{7}$$

where $x_{ai} \geqslant 0$ for $a \in A$ and $i \in [T]$ denotes the flow on arc a in time period i, and $y_{ai} \in \{0, 1\}$ for $a \in J$ and $i \in [T]$ indicates when the arc a is *not* shut down for maintenance in time period i.

We present a branch-and-bound algorithm called the "Partial-State algorithm" to solve the problem for *single transhipment node networks* i.e. networks with $|V| = 3$. Unit processing time of each job leads to formation of symmetries in the solution space. We include powerful symmetry breaking rules in the algorithm to make it more efficient. We provide an easily-computer combinatorial expression that is proved to give the value of LP-relaxation of the problem at each node of the branch-and-bound tree. We also provide another upper bound which is even stronger than the LP value at each node of the tree, and show how this improves the run time of the algorithm.

Keywords: *Network models, maintenance scheduling, mixed integer programming, branch and bound*

Modelling the Capacity of the Hunter Valley Coal Chain to Support Capacity Alignment of Maintenance Activities

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Abstract: The Hunter Valley coal supply chain (HVCC) is the system of logistics facilities – principally a network of rail track and three coal handling terminals – enabling coal mined by producers in the Hunter Valley to be transported, assembled, and loaded onto ships for export. The HVCC serves around 11 producers operating through more than 30 coal load points in the Hunter Valley, transporting coal over rail track extending around 450 km inland, managed by two track owner/operators, via rolling stock from four rail haulage providers that make around 22,000 train trips for approximately 1,400 vessels per year. The HVCC now delivers around 140 million tonnes of coal per annum (Mtpa), with the port of Newcastle exporting more coal by volume than any other facility in the world.

The Hunter Valley Coal Chain Coordinator P/L (HVCCC) is the organization at the heart of this logistics operation. In a landmark for collaborative logistics, the HVCCC was established by HVCC stakeholders to plan and manage the valuable shared infrastructure of the system. The HVCCC provides a range of services vital to the planning and delivery of coal through the logistics system, with its core task to improve the capacity of the coal chain through a centralised planning process.

One of the key ways in which this task is achieved is through the alignment of maintenance activities. All key assets in the HVCC (e.g. rail track sections, coal stacking machinery, terminal conveyor systems) undergo regular preventive maintenance, planned well in advance. While undergoing maintenance, an asset cannot function to deliver coal (or can function only with reduced capacity), thus reducing the capacity of the system. However astute scheduling of these planned maintenance activities releases latent capacity. Such astute scheduling is referred to as *capacity* or *maintenance alignment*, and is a core function of the HVCCC.

The maintenance alignment process at the HVCCC is supported by a model of the system capacity, which quantifies the impact of maintenance activities on the system. This was originally achieved with the assistance of a manual model created in Microsoft Excel, which used as input the impact of each maintenance activity on key assets in the HVCC in terms of the reduction in tonnes per hour that the asset could handle. This was further developed by HVCCC in-house to the current production application known as the Annual Capacity Model (ACM), written in Microsoft C#.net stored in a Microsoft SQL database with business rules stored in Common Knowledge. This application, whilst fit for purpose, has limited scenario testing capability and no optimisation functionality. These issues were a catalyst for collaboration of the HVCCC with the University of Newcastle, leading to the development of two separate but symbiotic prototype optimisation applications: the Capacity Evaluator and the Maintenance Optimiser. The former builds on the model concepts and logic of the current HVCCC ACM to estimate system capacity for a given maintenance schedule. The latter reschedules maintenance activities so as to maximize system capacity.

This paper focusses on the Capacity Evaluator (CE) application, and the recent enhancements to it that have facilitated its adoption. Based on a Linear Programming (LP) model, the CE constructs flows of coal over time so as to maximize total throughput, and offers new features, such as the ability to integrate in-bound and out-bound flows of coal at the terminal stockyards and account for greater complexity in the rail network. However the LP technology also presents new challenges: multiple optimal LP solutions mean that minor changes in input data can result in major variations in patterns of flow observed in the solutions. This paper reports on how this challenge was converted to an opportunity: flexibility in optimal solutions is exploited in a multiobjective approach to achieve flows consistent with contractual targets, while sacrificing little or nothing in terms of throughput. Both the mathematical modelling and decision support processes needed to achieve this, and to ensure the tool is fit for purpose, are described.

Keywords: *preventive maintenance, maintenance scheduling, multiobjective linear programming*

EXTENDED ABSTRACT ONLY

Simulation and Optimisation for Bulk Terminals

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Abstract: Bulk terminals are the gateways for Australia's coal and iron ore exports which are currently the key drivers of our national economy. On the opposite end of the global supply chain, similar bulk terminals are supplying much needed raw materials to the world's fastest growing economies in India and China. These terminals provide a critical link in resource supply chains acting as the transport interface between land and sea. With large differences in carrying capacity between trains (typically thousands of tonnes) and ships (up to 200,000 tonnes and beyond), bulk terminals must provide sufficient storage to cater for this imbalance. Another function performed within bulk terminals is blending of ore from various sources to ensure the properties of the ore meet specifications required by the end customer. Physically, bulk terminals may include several rows of stockpiles, train dump stations, stackers, reclaimers, surge bins, sample plants, transfer towers, berths and ship loaders, all connected by a network of conveyors. Simulation and optimisation are powerful tools for the design and operation of bulk terminals. Simulation is typically used during the design process to predict and compare system performance for a range of possible terminal designs. Detailed simulation of bulk terminals can be challenging because of complex decision making required to simulate an efficient operation (as would be achieved by human operators). Optimisation embedded within the simulation model is often required to effectively deal with these complex decision problems.

An example of such an optimisation problem arose in a recent Australian east coast coal terminal simulation model. Given the current state of the terminal, requests to reclaim product for loading vessels, requests to stack product for unloading trains and the availability of equipment chains, the problem is to allocate a pairing of stockpile and equipment chain to each request to maximize equipment utilization subject to movement and proximity constraints. This mini-optimisation is solved thousands of times throughout the simulation whenever equipment becomes available for reallocation or new requests enter the system.

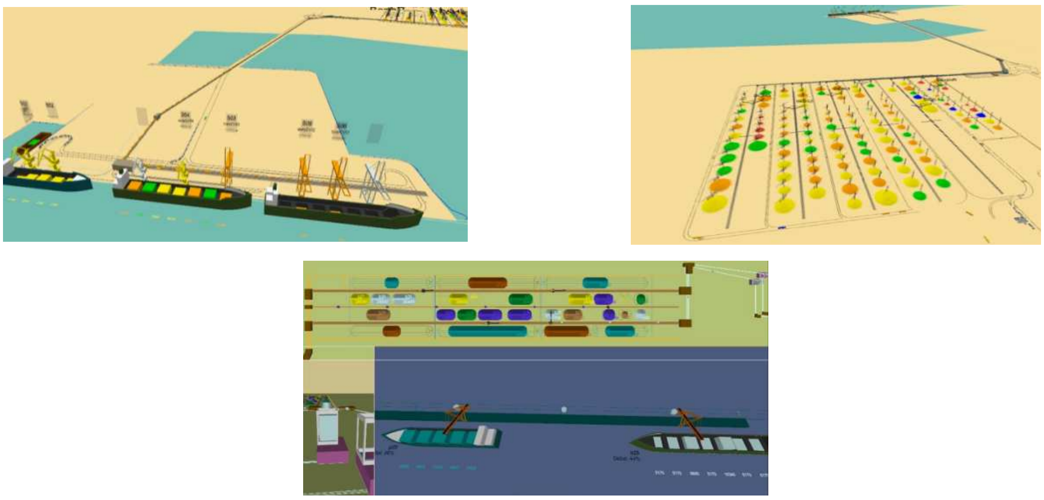

Figure 1. Screenshots of materials handling simulations developed for Aurecon projects.

Another challenging aspect of bulk materials handling simulation is the dependence of instantaneous and average reclaiming rates upon stockpile geometry. The typical approach is to assume a blanket system average and apply this constantly throughout the simulation. In reality, the long-term average reclaim rate achieved depends on average parcel size and stacking method used. The accompanying presentation will describe a new development at Aurecon, which is to explicitly model the evolution of stockpile geometry and its impact on instantaneous reclaim rate.

Keywords: *simulation, optimisation, mining, resources, logistics*

High-Order Multi-Objective Optimisation of Complex Water Resources Systems under Climate Change

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Abstract: Optimisation studies in water resources management are seldom represented using three or more objectives; the so-called 'high-order' multi-objective optimisation problems (MOOPs). To date the multi-criterial nature of such problems has been reduced in order to overcome the high computational effort involved and to facilitate the communication of complex modelling results to decision makers. Recent examples of planning processes around the world highlight the need for ways to develop sustainable operating strategies that explicitly incorporate all interests to water.

Moreover the need to identify a suite of (trade-off) optimal operating strategies is further challenged when dealing with high-order MOOPs. Visualisation of optimal solutions for such problems has always been a daunting task since the conception of multi-objective optimisation. A high-order MOOP is formulated for the Wimmera-Mallee Water Supply System; a complex multi-reservoir system located in Western Victoria (Australia) that is operated to meet the needs of a range of water users.

An optimisation-simulation modelling technique is applied to the system in order to identify the optimal operating strategies assuming six objective functions are used to measure the sustainability of the system under historic and forecast hydrologic conditions over a 100-year period. The aim of the study is to demonstrate the usefulness of a 'sustainability index' in order to evaluate and compare various long-term optimal operating strategies. The results show that a sustainability index can be used to assist decision makers to consolidate their search for preferred solutions from a set of optimal operating strategies in high-order MOOPs.

Keywords: *optimisation, modelling and simulation, water supply systems*

An interactive decision support system for open-pit mine production

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Abstract: In this presentation, an interactive decision support system is proposed for the open-pit mining industry. This decision support system mainly integrates mid-term block sequencing and short-term production scheduling modules. The mid-term block sequencing module intends to determine the optimal sequence of blocks mined over medium time periods to satisfy tactical targets under capacity constraints of mill plants, waste dumps, stockpiles, etc. The short-term production scheduling module solves multi-resource multi-stage mine production scheduling problems in order to optimally allocate mining resources at various processing stages and determine tasks' starting and finishing times in the most effective manner.

The proposed decision support system is a promising toolbox for the mining industry to optimise the whole open-pit mining production process in an interactive and systematic way.

A series of mixed integer programming models for short-term mine production scheduling problems under a variety of realistic mining constraints are developed within this integrated system. The proposed hybrid approach, which integrates the exact MIP solver CPLEX and the heuristic algorithms after decomposition, is developed to solve different-sized instances.

The proposed decision support system has been applied to a real-world mining project with the cooperation of an Australian mine site. An insight-provoking case study based on real-life mining data was conducted to verify that the proposed models can significantly improve the performance of the open-pit mine production process.

Keywords: *open-pit mining, mine production, planning and scheduling, decision support system*

Modelling scheduled rail operations within a dynamic mine to port supply chain simulation

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Abstract: Due to an energy provider's plans to increase coal exports from mines in the South West of Western Australia, upgrades to supply chain infrastructure are required. In particular the existing single track railway connecting the mines in the Collie region to the South West Mainline and Bunbury Port are likely to require additional passing loops and sections of dual tracking.

Brookfield Rail, the below rail owner, commissioned AECOM to advise on the likely rail upgrades that would be required. AECOM developed a discrete event simulation model of the supply chain however, unlike traditional pit to port models, trains could not operate on a 'run when ready' basis. Brookfield Rail operates the railway on contracted, scheduled paths for a variety of users and the model needed to reflect this to provide realistic capacity results.

Existing rail network user-paths were to be maintained and cycle times for the new coal trains could not exceed 12 hours. All users were to be treated with equal priority. A realistic balance between scheduling paths whilst retaining the ability of the system to dynamically respond to unplanned events was agreed, which was then implemented in the model.

Train Performance Calculations (TPC) were also undertaken to determine sectional running times for standard and maximum length consists for each option. Speed profiles were produced and sectional running times calculated.

In-Train Forces (ITF) modelling confirmed the feasibility of the different maximum length train options. For both axle loads the maximum consist length was investigated based on choice of locomotives, wagons and couplers. Outcomes from TPC and ITF informed the inputs to the discrete event simulation model.

Due to the efficient model implementation a large number of scenarios were able to be modelled that varied axle load options, maximum train lengths, numbers of train consists, mine loop locations, loading rates, additional sidings and various track duplication options.

The impact of the new trains on other network traffic was determined by monitoring level of late running and average lateness in the supply chain simulation model. The model was used to recommend capacity upgrades that reflected realistic running of the railway without negatively impacting on other rail users. The simulation was developed to be flexible enough to dynamically model terminal operations at the mine and port whilst interfacing with the scheduled rail operations. The modelling identified a choice of infrastructure upgrades which could achieve the additional capacity without negatively impacting existing system users.

Keywords: *Decision support system, simulation, capacity analysis*

A GIS model for simulating infrastructure investments in livestock logistics: Application to the northern beef industry

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Abstract: Australia's northern beef industry of 12.5 million head is characterised by supply chains of long travel distances, and high vulnerability to variability in climate and external markets. With transport costs being up to 35% of farm gate price, infrastructure investments in roads, bridges and holding yards, have the potential to substantially improve viability and resilience of the expanding northern industry. However, there has been no tool available to holistically evaluate a range of such options and benefits across each enterprise. To address this issue a project was funded by the Commonwealth and State Governments to develop three logistics models in simulation and optimisation, each of which is designed to analysis a range of options. In this paper, we outline one such model, based on GIS, that is designed to simulate the transport cost implications to enterprises across the livestock supply chain from infrastructure investments and changes to driver/animal welfare policy. It does this by estimating the transport costs for all livestock movements between enterprises in the northern beef industry, accommodating road conditions, vehicle access restrictions and tick clearing. A feature of the methodology is that it accounts for high granularity of individual vehicle movements between property, abattoir and port, as well as the ability to scale up to an almost complete view of logistics costs across the entire beef industry of northern Australia. We demonstrate the model using case studies of: upgrading highways in Queensland; removing tick clearing requirements for cattle transported to abattoirs; and a new abattoir south of Darwin..

Keywords: *transport, infrastructure, simulation, beef, northern Australia*

CAGE Experimentation – Translating the Principles of Peer-to-Peer Distributed Simulations Design into Practice

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Abstract: The Coalition Attack Guidance Experiment (CAGE) is a campaign of coalition warfighting experimentation conducted under the sponsorship of TTCP across Australia, Canada, United Kingdom, and the United States. The CAGE experiments are conducted as distributed peer-to-peer federated simulations and peer-to-peer Command and Control relationships. The distributed federated simulation environment includes: OneSAF, JSAF, JCATS, FLEWSE, and VBS2 across the nations.

This paper focuses on the challenges of designing coalition warfighting experiments for the CAGE campaign of experiments, where the simulations are distributed and federated across the nations; where the simulations are heterogeneous; and where different simulations require different levels of fidelity in modelling the entities. Substantial research has been conducted into distributed peer-to-peer simulation design. The results of this research have been codified into sets of design principles by IEEE and the Simulation Interoperability Standards Organisation and codified into Simulation Federation Agreements. The research to-date has focused on the principles of distributed simulation design, not the pragmatics of DIS entity mappings, allocation of DIS entities to simulations, nor the validation and verification of the federated simulation behaviour.

The problem domain for the CAGE campaign of experiments is cross-boundary targeting. Current operations have exploited advances in digital Intelligence, Surveillance, Reconnaissance, and Electronic Warfare flows and precision-guided munitions to enable the successful prosecution of mobile emergent targets. In the tactical battlespace, it is possible that mobile emergent targets will cross the area of operations boundaries between units and nations, or that the assets required to find, and prosecute, mobile emergent targets will be drawn from multiple units or nations. The impact of mobile emergent targeting on coalition warfighting experimentation is that individual actors have significant effects in the battlespace. As a result, some of the modelling needs to occur at the individual level to enable these effects in the battlespace.

At The Technical Cooperation Program (TTCP) level, the Joint Systems Analysis Technical Panel 8 Combined Fires and Demonstration panel has been directed to develop a supplement to the TTCP GUIDEX (on warfighting experimentation) for the pragmatics of conducting distributed experimentation design and a distributed simulation design methodology. This paper will describe the first attempt at the distributed simulation design methodology that was implemented for the CAGE IIIA experiment in 2013.

Keywords: *warfighting experimentation, distributed simulation, command and control*

A Combined Bayesian Belief Network Analysis and Systems Architectural Approach to analyse an Amphibious C4ISR System

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Abstract: As an amphibious operation encompasses the land, air and sea domains, it is a Joint Operation, involving all three services. More than any other military operation, the success of an amphibious mission requires the extensive synchronisation of both physical and informational assets across the joint force. Vital to this synchronisation is an effective and reliable Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) system. Consequently, in supporting the development of the ADF's amphibious capability, the Defence Science and Technology Organisation (DSTO) was involved in modelling the operational effectiveness of this joint amphibious capability with a focus on the impact of C4ISR. In this paper, we describe our staged approach to develop a C4ISR focused Bayesian Belief Network (BBN) model of amphibious operations via a higher level cause-effect concept map and a BBN.

BBNs were selected as they provide a means to both graphically represent the cause and effect relationship between various elements within a scenario as well as to quantify their likely impact on the outcome. As part of this approach, we propose a methodology to link BBNs with discrete information exchange requirements as a means of capturing the operational impacts of C4ISR. Such an approach can potentially provide both the detail on the availability of information products during various tactical phases of an operation as well as the probable operational impact of any deficiencies. Consequently, it is possible that both commanders and capability developers can make more informed decisions and trade-offs under conditions of uncertainty.

Keywords: *Bayesian Belief Network, System Architecture, Defence, C4ISR*

Operational Synthesis for Small Combat Teams: Exploring the Scenario Parameter Space Using Agent-based Models

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Abstract: Combat simulations and wargames form part of a suite of tools used in the analysis of military operations. Operational synthesis is a technique that integrates a class of models known as agent-based distillations (ABD) into the analytical process. ABDs are a subset of agent-based simulations that deliberately distil the modelling variables in order to focus on those that are important for the purposes of the study. This property makes ABDs particularly useful for the rapid exploration of large parameter spaces, something that is not typically feasible in high-fidelity military simulations due to resource and computational constraints.

In this study we explore the utility of the operational synthesis approach in the context of the performance of small combat teams conducting close combat in an urban setting. We examine the ability of the Map Aware Non-Uniform Automata (MANA) ABD to independently identify trends that are consistent with those found in a previous study that was conducted using a mix of wargaming and high-fidelity closed-loop simulation with the Close Action Environment (CAEn) tool. The CAEn study developed a scenario to assess the impact of various manned and unmanned vehicle options on the combat performance of a small combat team for the break-in and clearance of a small village. We modelled the same scenario in MANA to explore the impact of terrain density and opposition tactics and force size on the outcomes.

The results from the implementation in MANA show trends consistent with the CAEn study. Some noticeable differences were observed in the case of civilian casualties but these results can be attributed to known limitations of both the CAEn study and some parameters in MANA. We also identify additional insights that warrant further study with other tools and techniques. Further work is also required to determine if similar outcomes can be achieved for a range of different military scenarios. If the results from studies conducted using ABDs consistently align with other studies then ABDs would be a valuable addition to the suite of military operations analysis tools given their ability to explore vast parameter spaces in a relatively short period of time. ABDs such as MANA could then be exploited to provide initial insights during the problem definition and design stages of relevant military studies and also to add robustness during the analysis phase.

Keywords: *Agent-based modelling, Defence, Simulation, Operations analysis*

Balancing the Validity and Viability of Bayesian Belief Networks for the Study of National Strategic Decisions

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Abstract: National strategic decisions to employ military force are characterised by high levels of uncertainty regarding threat and actor motivation; political sensitivity regarding consequences; and a lack of clarity regarding influences and objectives. By understanding how these factors have interacted historically to impact on decision outcomes in different situations, strategic analysts are able to provide more informed analysis of current strategic options and therefore better advice to decision makers. Bayesian Belief Networks (BBNs) provide a powerful method to study past decisions as they capture both qualitative insights through concept mapping regarding decision maker rationale, as well as their likely impact on national objectives. Additionally, they readily incorporate subjective human input in both the construction of concept maps and through conditional probability assessments. However, there are a number of problems experienced in constructing BBNs to study these decisions. Of particular concern is the viability of the BBN structure for data capture. If a BBN is too complex a busy decision maker may be required to make an unacceptably high number of probability assessments. In order to make BBNs viable in this setting, an approach is required that simplifies the data capture from the point of view of the decision maker and manages the impact on model validity within a defendable and transparent process.

This paper takes a practitioners view on the application Bayesian Belief Networks (BBN) to study past national strategic decisions in order to inform future decision making. The intent is to propose a framework to structure BBN studies in an environment in which subject matter experts are dispersed, requiring time and money to meet them for data elicitation interviews, and where they are often busy and only able to provide a limited time for data elicitation. The focus of the framework is therefore on how to develop a BBN to study national strategic decisions in such a way so as to minimise the elicitation burden while managing the impact on the validity and integrity of the modelling. First, the advantages and data elicitation challenges of using BBN for studying political-strategic decisions are discussed. Next, various strategies and techniques from the literature regarding reducing the data elicitation burden are reviewed and illustrated, where appropriate, by examples from a recent data elicitation activity to develop a BBN on political-strategic decision making. Finally, selected strategies and insights from the recent data elicitation activity are combined into a proposed data elicitation framework that manages this trade-off between viability and validity.

Keywords: *Bayesian Belief Networks, National Strategic decisions, Data elicitation*

Data Collection at Defence and National Security Exercises

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Abstract: Analysts use field events such as experiments, trials and exercises to meet a variety of data collection objectives. These may involve collection of data for determining the effectiveness of equipment or procedures, scoping future studies or informing model development. Over the last 18 years the authors have been engaged in a variety of field *exercises* and *experiments*. Unlike *experiments*, which are generally run by and for the analyst, *exercises* are run for the benefit of the exercising unit or to meet some higher level objectives. Consequently, analysts have limited control over events and often need to work with the exercise as given; significantly reducing data collection opportunities. Despite these difficulties exercises provide a higher degree of realism than staged experiments or trials.

Engagement in Defence and National Security experiments and exercises identified ten key differences that necessitate alternative approaches to data collection. Amongst these factors are the issue of experiment/exercise design and the impact on data collection opportunities as well as the various mechanisms by which the presence of an analyst can impact a free play activity compared with a controlled experiment. Several approaches have been employed to offset these issues and enhance the opportunity and value of data collection during exercises.

In previous work we observed that the concept of perceptual positions provides a useful framework for considering different forms of data collection. These perceptual positions include: 1^{st} (self), 2^{nd} (other) and 3^{rd} (detached observer). When applied to data collection during field activities these respective positions generally relate to subjective (e.g., observations of participants of the activity gathered during interview), speculative (e.g., opinion or interpretation of actions by subject matter advisers) and objective (e.g., impartial observations including instrumented data collection). Together these three positions can be used to build up a more complete picture of the system under study.

Attendance at Army exercises during the early years of Australia's Soldier Modernisation program sought fundamental information on how the Army operated. Much of the information provided by subjects was a mixture of first-hand experience (1^{st} position) and generalisation (2^{nd} position). These were complemented by objective measurements made by the analyst (3^{rd} position). Perceptual positions provided a framework that facilitated engagement with participants and subject matter advisors (SMA) by placing their "observations" into an appropriate context. Similarly, the study of a Police Operations Centre (POC) during National Security exercises demonstrated the benefit of the perceptual position approach. The objective (3^{rd} position) video data of the activities of the POC commander was used to facilitate post exercise interview (1^{st} position) and examine the differences between the two exercises investigated (2^{nd} position). In both cases useful understanding of the system was developed in the absence of statistically valid volumes of data.

Pre-exercise planning and liaison is another mechanism by which analysts can significantly enhance the data collection opportunities associated with attendance at exercises. One specific example was a study of Army engineers. Pre-involvement of analysts with the exercising unit proved especially useful in gaining participation of the stakeholder group which contributed to the preparation of an IDEF0 diagram. Analyst/military teams were also utilised during this exercise which led to better integration of the analyst within the exercising unit. Providing the perceptual position framework to SMA also enabled them to act as surrogate analysts and helped in the planning and execution of data collection activities.

Our conclusion is that a combination of pre-planning and the application of the perceptual positions framework can overcome many of the issues associated with the collection of data during field exercises. Furthermore the consideration of data collection from different perceptual positions can facilitate improved preparation and planning of the exercise and supports the development of effective analyst/military teams. Under the right circumstances exercises become a shared activity between the analyst and the stakeholder community that provides a significant opportunity for the collection of realistic and meaningful data.

Keywords: *Data collection, exercises, experiments, perceptual positions*

Bayesian Evolved Multi-Criteria System Risk Evaluation

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Abstract:

Risk assessment is the key exercise in the management of all Defence Projects. DSTO provides assessments for technical risks of Defence system/capability acquisition projects. The important component of the technical risk assessment is to accurately evaluate the readiness levels of the technologies, system integration, and technical providers/ manufactures (TRL, IRL, and MRL) and then transfer those into estimation of impacts/risks on project costs, schedule, and system performance.

There are many approaches intending to address the risk assessment for complex systems. However, most of those are static methods for a certain stage of the project. The validation of the assessment results sometimes could be difficult. Because of lack of supporting data at the early stage of the project, the credibility of assessment could also be low. This is particularly true for the systems under the development. The reliable and up-to-date estimation of the readiness levels in the risk assessment is essential to ensure the success of the project.

This study extends the recent application of the multi-criteria decision analysis (MCDA) to Defence Project Management by

(i) introducing Bayesian upgrade of TRL, IRL and MRL for the systems and critical sub-systems, and
(ii) allowing more flexible models for estimation of impacts of the project immaturity.

The tool developed in this study can help the Project Science and Technology Advisor (PSTA) to dynamically monitor the evolution of the project via Bayesian up to current information taken; maintain the credible records through every Bayesian update history; trace and control the risks, and properly allocate the project resources, re-schedule the task plan, and decide the trade-off of the system performance by the multi-criteria analysis assisted by the flexible immaturity induced impact model.

Keywords: *Risk evaluation, Bayesian evolved, multi-criteria*

A Feasibility Study on Bayesian Approach for Weapon System Test and Evaluation

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Abstract:

The traditional binomial approach for evaluating weapon system reliability and performance through full system trials/tests is well established for system acceptance testing. However, significantly added value could be achieved if a Bayesian approach were used. Some important benefits may include:

1. Inclusion of various operational test conditions (i.e. releasing test constraints).

2. Integration of all available data/information into the test and evaluation (T&E) methodology.

3. Allowance for an evolving T&E program (i.e. finding removable faults and improving system reliability during T&E phase).

4. Potential to achieve the proper test decision with a smaller sample size.

This paper evaluates the feasibility of a generic Bayesian approach for fully integrated weapon system acceptance tests; reviews technical aspects of this approach; and outlines the basic technical frame of building a Bayesian model to support trial tests, lab tests/experiments, simulation, and intelligent information collection of the system under test.

The weapon systems under T&E are complex, and the configurations of subsystems or the processes of system operation are mixed parallel and serial functions. The prior could be various forms of distributions and characteristics (for example, both non-informative and improper priors may be used in a certain stage of T&E). Therefore, it is a challenge to construct the overall system reliability and performance model. However, the experience in building subsystem models and system integration, in lab tests and field trials, and in weapon system data collection would provide a sound base for a feasible overall system modeling. Some examples are discussed in this presentation.

While a Bayesian approach offers the possibility of adding value to T&E, it may require additional input data and information, significant computational efforts, continuous support to monitor and diagnose the system T&E, and a sophisticated understanding of both statistics and the system under test.

Given the high cost of full system tests/trials and system complexity, a Bayesian approach warrants the effort to conduct further studies and possible implementation in the weapon system T&E processes.

Keywords: *System Test & Evaluation, Bayesian approach*

Enabling Models of Partially Understood Red Forces

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Abstract: Modelling of conventional opposing military (red) forces can be treated as a straightforward extension of description of own (blue) force. Where the red force is irregular or operates in a non-conventional manner, alternative modelling approaches need to be followed. Hence not only structural/organisational issues need to be considered but also methods of operations, goals and beliefs need to be included. For example: seminar war games are not suitable as they only look at part of the issue. Such red forces are at best partially understood thus adding a complicating factor to an already difficult exercise. Nevertheless, analysts do need basic models (which we call enabling models) on which to explore red force capabilities and vulnerabilities and thus to advise decision makers on appropriate blue force actions and structures. This focus on both the blue and the red forces is implicit to the overall Joint Military Appreciation Process (JMAP).

In our work to develop such models we note that there are many distinct approaches that could be followed. Of course, any model needs to be fit for purpose though it is our belief that only a limited set of enabling models needs to be considered and these can be the basis of a portfolio of models for further studies. For instance, constituent elements, descriptions of actions and operational business processes all provide a means to build pictures of the red force. Understanding and exploitation of these models provide both low level (tactical) and high level (strategic) options for blue. In this paper we describe, how some of these tools can be used to generate enabling models of partially understood red forces.

Enabling models can be used to gain an understanding of the system, improving the system or exploring the system and the models that are explained in this paper contribute to any of these. Enabling models may also be used to identify data collection requirements to develop more analytically useful tools. In this paper, we have used the established intelligence equation as the basis of our modelling strategy. The three elements: capability, opportunity and intent are the information acquired of the adversaries and provide an understanding of the threat environment. By combining information on the red capability with their intent and opportunity, the blue forces can effectively defend their own capability and attack red vulnerabilities. Red capability information includes the structural elements implicit in raising, training and sustaining a force. The red intent would include the cultural belief and things that motivate them to attack the blue and the opportunity can be equated to understanding the red TTPs during engagement of the red versus blue. For effective blue force planning against the red, enabling models should aim to understand:

- "what" constitutes the red capability including their structure and networks;
- "why" they want to attack the blue, i.e. the purpose and intent of their actions and
- "how" they are likely to take advantage of blue vulnerabilities.

This approach is similar to the four element police equation (opportunity, motive, weapon and victim) where capability equates to the weapon, intent relates to motive, and opportunity to opportunity and victim.

In this paper, we describe three types of enabling models, namely engagement models, structural/organisational models and business models. The goal of engagement models is to identify military vulnerabilities of the red force and looks at the answering the "opportunity" aspect of the intelligence equation by denying the red force tactical or operational advantage. The structural/organisational model helps to understand red force "capability" and helps to deny the red force the ability to conduct operations. Finally the use of business models help in understanding the "intent" and goals of the red force and is intended to deny the red force of belief driven support.

Finally we have used ease of population, ease of finding issues and ability to comment on changes, as the three sets of criteria for choosing a technique. Each of these techniques is analysed to see if they can be beneficial for blue force analytical campaign. Finally we have tried to evaluate each of these models based on the "fitness for purpose", by analysing each of these criteria although we acknowledge that an accurate representation of poorly understood systems cannot be achieved.

Keywords: *Problem structuring, soft OR models*

The US Army's Force Generation Process – To Simulate, or Not to Simulate

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Abstract: The focus of this presentation is on a model of the US Army's force generation process. That is, the process by which the Army provides manned, trained, equipped units to combatant commanders.

In 2004, the study team faced a series of questions. The crux of the matter: the Army's readiness policy had to change from one that generates forces primarily for sudden contingency operations to one that sustainably delivers forces for enduring operations. What should that process look like? How should the Army structure itself to meet demands via the new process? And what is the Army's mission capacity under various force structure and force generation options?

The team built a simulation model called MARATHON. It went into use immediately and remains in use. The presentation will discuss how they built the model and what they learned in the process of building it.

Whether or not to simulate was a point of debate. The author will discuss what led to the decision to simulate, along with lessons that the study team learned because they used a simulation model, as opposed to other alternatives.

Keywords: *Defence, Force Generation, Force Structure Analysis*

A Characterisation Construct for Capability Considerations

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Abstract: In supporting current military operations there is often a desire to identify and field new capabilities as rapidly as possible to support personnel. Capabilities are thus rapidly assessed against endorsed criteria determined by circumstances of the moment and fielded amongst multiple recipients. Each of the capability recipient groups then build-up their own usage history with the delivered capability that couples with their implicit and explicit requirements. As opportunities are presented to further upgrade the capabilities, the capability manager needs a framework to unpack the implicit and explicit factors associated with the usage history in order to make informed decisions on the future capability direction. Resolving resulting capability concerns, especially when the difference between previous and new capabilities may be associated with implicit factors, presents an ongoing challenge.

For a specific capability, in an effort to address the desire for rapid (consistent) assessment and aid in resolving concerns from multiple user communities, the following approach was adopted. The multi-disciplinary approach provides context, system boundaries and makes as many implicit concerns explicit amongst the multiple communities so that from the common understanding the capability manager can make an informed decision. Further, by following the proposed approach a standardised library of information on the instantiations of the capability types can be formed allowing for suitable comparisons to be undertaken between past and newly tested capabilities.

The multi-disciplinary approach, named a characterisation construct, consisted of the following six components to assess a particular capability: (i) Threats: consisting of endorsed representative cross section; (ii) Environment: representative expected types; (iii) Technical: the physics related aspects governing the performance (ideally operator independent); (iv) Human/Design: design factors and the factors associated with operator engaging with the capability; (v) Operational: the expected operational context governing use of the capability; and (vi) Logistics/Training: the predicted logistics and training required to sustain the capability. It is important to note that these six areas are not orthogonal to each other, i.e. they have varying levels of inter-dependency. However by separating into these components it is possible to apply well established processes to gather information which can then be combined into an overall view of the capability to enable holistic comparisons to occur.

During the talk, the methodology and its application will be discussed in the context of a particular capability concern and some lessons presented.

Keywords: *Capability decision making, military operations, multi-disciplinary*

EXTENDED ABSTRACT ONLY

A Campaign of Experimentation Employing M&S at the CFWC

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Abstract: The Canadian Forces Warfare Center (CFWC) was established over a decade ago initially as a joint experimentation centre driven by modelling and simulation. It has since grown and is now the home for both the Canadian Armed Forces' Joint Lessons Learned Branch and Joint Doctrine Branch and also has a mandate to conduct joint training. The CFWC has been succeeded in conducting campaigns of experiments both nationally, for the Joint Fire Support Technology Demonstration Project, and internationally in the Coalition Attack Guidance Experimentation (CAGE) campaign.

The CAGE series is a campaign of coalition warfighting experiments conducted under the sponsorship of The Technical Cooperation Program (TTCP) across Australia, Canada, the United Kingdom, and the United States. The CAGE experiments are conducted with distributed peer-to-peer federated simulations and peer-to-peer command and control (C2) relationships. The most important component of these experiments is the subjects – recent veterans of operations experienced in the C2 process and technologies under examination in the experiments.

The presentation will describe how Canada has participated in CAGE and the major findings from the most recent experiment, CAGE II. It will provide information on the integrated testbed and the network that supports the experiments, the process used to plan and run the experiments, and the people and skills at the CFWC that make it all happen.

Within TTCP, the Joint Systems Analysis Technical Panel 8 - Combined Fires Demonstration and Experimentation - has been directed to develop a supplement to the TTCP GUIDEx for design of distributed experiments, including the methodology for designing distributed simulation. The presentation will provide some initial lessons for this supplement.

Keywords: *Experimentation, command and control, modelling and simulation*

Cost-effective capacity testing in the Australian Army

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Abstract: The Australian Army's ability to undertake new or existing contingencies is dependent on its capabilities and the capacity it holds of each capability to conduct multiple contingencies simultaneously. Capacity is determined not only by the number of assets that are available, but also the way in which they are organized. Armies must therefore review their current and future force structures against their anticipated tasking in order to ensure they have adequate capacity. However, full-scale reviews or tests can be expensive and time-consuming.

In this paper we present a cost-effective largely qualitative methodology for testing an Army's capacity based largely around structured planning and assessment processes. This was demonstrated in an experimental environment comparing the Australian Army's current organizational structure to two hypothetical future structures. These were: Centralized, where assets were managed in a single Headquarters; and Decentralized, where assets were managed by a number of distributed Headquarters.

Each structure was evaluated on its ability to meet the requirements of concurrent military operations, drawn from future operational planning guidance. Three syndicates, comprising military and civilian Subject Matter Experts, were each assigned one structure, and worked through a systematic process of allocating assets to tasks. Structures were graded by the syndicates and by independent experts on their ability to meet the tasking requirements.

The methodology was able to identify weaknesses and deficiencies in each of the structures. Some limitations of the methodology and recommendations for future use will be discussed.

Keywords: *Methodology, capability, organizational structure*

Dynamic Morphological Exploration

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Abstract: Morphological Analysis of even moderately complex systems, can lead to large (often unmanageable) state spaces. In many contexts, the expense of testing or exploring a single state can make exploration of the entire state space prohibitive. To temper this, techniques and software packages have been designed to assist the analyst in 'spanning' the total morphological space using a minimal number of assessments.

However, the authors have noted situations where the determination, *a priori,* of a (static) set of states to test has led to highly sub-optimal exploration of the problem. This has been due to the analysts not being able to predict, and account for, the results of complex interactions of all the variables. Initial assumptions on the magnitude of impact from minor factors has canalised the analysis plans down dead-ends.

To address this problem, and extension of General Morphological Analysis is proposed: Dynamic Morphological Exploration.

The driving principle behind this method is to create an exhaustive tree mapping of optimal search paths, based on all possible outcomes of previous state space tests. The analyst is then able to refer to the Dynamic Morphological Exploration Tree during an experiment or analytical campaign to objectively decide the next set of parameters to tested. With sufficient fore-thought, the Tree will guide the analyst away from repetition and dead-ends.

This paper first describes the principles behind generating Dynamic Morphological Exploration Trees. It then uses an example to generate a sample tree and shows how this approach is superior to the more traditional approach of exploring Morphological Spaces.

Keywords: *Morphological Analysis, Scenario Analysis, State Space Exploration*

Pickup and delivery with a solar-recharged vehicle

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Abstract: Zimbabwe has one of the highest maternal death rates in the world. A key contributing factor is the difficulty that expectant mothers have in getting from rural villages to health care facilities. Specifically-designed electric vehicles, called African Solar Taxis, are currently being developed for deployment. The vehicles will be charged at solar charging stations located at health care facilities. The limited speed and range means that these vehicles must be efficiently scheduled so that expectant mothers are transported to health facilities in a timely manner.

We describe two methods for determining good single-vehicle schedules to transport expectant mothers to health facilities. We consider two objectives: maximising the total requested trip distance completed during the day, and minimising the schedule span. One of these methods is both simple and effective—it requires the scheduler to select from a list of precomputed trip patterns each day.

Keywords: *Pickup and delivery, electric vehicles.*

The two train separation problem on level track

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Abstract: We find driving strategies for two trains travelling on the same track in the same direction subject to given journey times so that an adequate separation is maintained between the trains and so that the total energy consumption is minimized. We assume the track is level.

Consider a single line rail track $[0, X]$ with signals placed along the track at points $0 = x_0 < \cdots < x_n = X$. It is a common safety requirement for trains travelling from $x = 0$ to $x = X$ that no two trains are allowed on the same segment (x_j, x_{j+1}) at the same time. We wish to find speed profiles $v_1 = v_1(x)$ for a leading train starting at time $t_{1,0} = 0$ and finishing at time $t_{1,n} = T_1$ and $v_2 = v_2(x)$ for a following train starting at time $t_{2,0} \geq 0$ and finishing at time $t_{2,n} = t_{2,0} + T_2$ such that the safety constraints are observed and so that the total energy consumption is minimized.

We solve the problem in two stages. For the first stage we consider a given set of times $0 = s_0 < \cdots < s_{n+1}$ where $s_n = T_1$ and $s_{n+1} = s_1 + T_2$. At this stage we wish to solve two problems—the leading train problem and the following train problem. That is we want to find $v_1 = v_1(x)$ so that the leading train leaves the point $x_0 = 0$ at time $t_{1,0} = 0$, passes through the points x_j at time $t_{1,j} \leq s_j$ for each $j = 1, \ldots, n-1$ and reaches point $x_n = X$ at time $t_{1,n} = T_1$ in such a way that energy consumption is minimized. We also want to find $v_2 = v_2(x)$ so that the following train leaves the point $x_0 = 0$ at time $t_{2,0} = s_1$, passes through the points x_j at time $t_{2,j} \geq s_{j+1}$ for each $j = 1, \ldots, n-1$ and reaches point $x_n = X$ at time $t_{2,n} = s_1 + T_1$ in such a way that energy consumption is minimized. By finding all sets of feasible appointed times $\{s_j\}_{j=0}^{n}$ it should be possible to choose the set of appointed times that minimizes the total energy consumed. We will consider systematic procedures for finding this best set of appointed times in another paper.

It is well known (Howlett 2000) that the optimal strategy for a train travelling on level track from $(x, t) = (0, 0)$ to $(x, t) = (X, T)$ is a *power-hold-coast-brake* strategy where the speed U at which braking begins is a uniquely determined function of the hold speed V. As the hold speed increases the journey time decreases. Thus there is a unique hold speed for each given journey time. For convenience we will call this an unconstrained strategy of optimal type. What happens to the strategy of optimal type when intermediate time constraints are imposed?

In the case of a leading train the intermediate constraints mean that the train must leave each section before some given time. If a proposed journey does not leave a particular section (x_{j-1}, x_j) before the appointed time s_j then the corresponding constraint $t_{1,j} \leq s_j$ is violated and the proposed journey is infeasible. In such cases the leading train must go faster on the first part of the journey$(0, x_j)$ in order to satisfy the active constraint $t_{1,j} \leq s_j$. Thus our intuitive idea will be that a strategy of optimal type for the leading train may use different hold speeds for different sections and as the journey progresses the hold speed will decrease.

In the case of a following train the intermediate constraints mean that the train must enter each section after some given time. If a proposed journey enters a particular section (x_{j-1}, x_j) before the appointed time s_j then the corresponding constraint $t_{2,j-1} \geq s_j$ is violated and the proposed journey is infeasible. In such cases the following train must go slower on the first part of the journey $(0, x_{j-1})$ in order to satisfy the active constraint $t_{2,j-1} \geq s_j$. Thus our intuitive idea will be that a strategy of optimal type for the following train may use different hold speeds for different sections and as the journey progresses the hold speed will increase.

In this paper we find precise formulæ that allow us to construct these intuitively optimal strategies for the leading and following trains. Note that our imposed constraints ensure that the following train will not enter any particular section until the leading train has left that section.

Keywords: *Optimal train control, train separation, constrained optimization.*

Simulation model of crossing pedestrian movements for infrastructure planning

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Abstract: Infrastructure planning requires an extensive knowledge of potential pedestrian behavior, in particular at high crowd densities. The modelling and simulation of pedestrian movements is an important tool in the planning and operation of airports, railway stations, sports stadiums, shopping malls, and other public places. For example, in shopping malls, optimal models are needed to guide pedestrians on predefined itineraries. Evacuation scenarios, where all individuals move toward the same escape point, can be interpreted as single destination problems. These have been studied quite intensively. Multidestination problems, where distinct streams of pedestrians move from one or more starting points to multiple destinations, need more investigation. In particular, the crossing of pedestrian streams has not yet been thoroughly investigated.

In the last decade, various authors have modelled pedestrian flows by a macroscopic approach. Pedestrians in dense crowds behave much like gas particles. Consequentially, pedestrian flows are often modelled by partial differential equations that are similar to those used in models for gas or fluid dynamics.

A more realistic modelling of crossing situations can be obtained by an adequate description of pedestrian behaviour in the presence of crowded situations.

An adequate description of pedestrian behaviour in crowded situations leads to a more realistic model. We assume that pedestrians try to evade crowded spaces. This effect can be modelled as a function of local density. Thus, our model is based on the assumption that pedestrians avoid densely populated areas by moving in the direction of the negative gradient of the total local density $\varrho = \varrho_1 + \cdots + \varrho_n$, where $\varrho_i,\ i = 1, \dots, n$ is the density of a particular pedestrian group. This local orientation can be interpreted as the behaviour of blind persons with canes, who generally stick to their planned direction, but modify it by moving away from congestion, i.e. they detect the gradient. The assumption of sighted people would lead to a nonlocal model, which is beyond the scope of this contribution.

Our model developed has the general form

$$\frac{\partial \varrho_i}{\partial t} + \nabla \cdot \boldsymbol{f}_i(\varrho_1, \dots, \varrho_n; x, y) = \sum_{j=1}^{n} \nabla \cdot (b_{ij}(\varrho_1, \dots, \varrho_n)\nabla \varrho_j), \qquad i = 1, \dots, n, \tag{1}$$

where $\boldsymbol{f}_i$ and $b_{ij} \equiv b_{ij}(\varrho_1, \dots, \varrho_n)$ with $1 \le i, j \le n$ denote the flux vector and the components of a diffusion matrix $\boldsymbol{B}$, respectively. Different populations moving in different directions are represented by different phases. In the framework of modelling by balance laws with mass, momentum, and energy equations, Equation (1) corresponds to the set of mass equations. The constitutive functions make the momentum equations unnecessary. In this system of convection-diffusion equations, the convective term corresponds to a movement towards a strategic direction and the diffusion corresponds to a tactical movement that avoids jams. The convective and diffusion terms are deduced from a general mass balance. Thereby, we derive a nonlinear diffusion matrix that is superior to the linear diffusion matrix

$$\boldsymbol{B}(\varrho_1, \varrho_2) = \begin{pmatrix} \varepsilon & \delta \\ \delta & \varepsilon \end{pmatrix}. \tag{2}$$

Keywords: *Passenger simulation, Infrastructure planning, Multiphase continuum model, Convection-diffusion equation, Finite volume scheme*

Comparative analysis of time-dependent shortest path algorithms: An application for a multimodal trip planner

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Abstract: A Multimodal Multi-objective Trip Planner (MMTP) has been in development at the Smart Transport Research Centre (STRC), Queensland University of Technology. It integrates the transit network, which is based on routes and timetables, with the road network, based on roads and intersections, via the use of park'n'ride facilities. It produces an optimal journey that can combine legs on both networks, and thus provides more flexibility to the user on how to travel to their destination, when compared to traditional single-network-based journey planners.

The use of real-time information from various sources, such as loop detectors, Bluetooth scanners and taxi GPS data can be used to predict the travel time along many of the roads in the road network in the near future, over the span of a couple of hours. The predicted travel time data can be used by time-dependent shortest path algorithms in order to produce more accurate and optimal journey plans. The provision of more accurate journey plans will allow the user to avoid congestion and arrive at their destination on time.

While the time-dependent shortest path problem was first defined in 1966, the vast majority of the research into this problem has only occurred in the last 20 years. One of the main discoveries made during this research is that if a time-dependent network obeys the First-In-First-Out (FIFO) property, then many of the algorithms that have been developed to solve the static shortest path problem can be adapted to produce solutions for this dynamic problem. A network obeys the FIFO property if the arrival time functions for its arcs are non-decreasing. In other words, if you were to leave from the beginning of an arc at time *t*, you should not arrive at the end of the arc after someone who left from the start at a later time. There have been several papers that have presented adaptations of a number of static shortest path algorithms, such as Dijkstra, A* and more complex hierarchical methods, so they can operate on dynamic time-dependent networks.

The prediction algorithm that uses the real-time information provides the MMTP with a time series of average travel times for a set of time intervals on the various links. This time series data is then used to construct a piece-wise linear travel-time function for each of the links, which obeys the FIFO property, and therefore can be used in the dynamic adaptations of static shortest path algorithms. Adaptations of both Dijkstra's algorithm and A* heuristic are implemented for the MMTP. This paper presents the equations and algorithms used by the MMTP in calculating time-dependent shortest paths.

The provision of real-time transit information has also begun to be more prevalent, with several transit authorities now providing realtime feeds. These provide various types of information, such as trip updates, service alerts and vehicle positions. The network used by the MMTP to represent the transit schedules is already a type of time-dependent network, albeit different from the road network as waiting is intrinsic for transit journeys. This paper presents the adaptations that have been made to the transit network graph in the MMTP in order to make use of the real-time transit feeds that are available. It also presents the issues and solutions that have been developed to produce integrated journey plans that use both the dynamic road network and transit network.

Finally, this paper presents the testing methodology that is used to produce computational results, and compare the results obtained from the various algorithms that have been implemented for the MMTP, using case-study problems based on the road and transit networks of Brisbane.

Keywords: *Multimodal trip planner, Dynamic shortest path, Time-dependent shortest path*

Train scheduling and cooperative games

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Abstract: We wish to determine how train operators should be rewarded when the sequence of trains using a rail corridor is changed from an existing plan to a more efficient plan. The time that each train finishes its journey depends on its departure time and on the progress of the trains ahead of it. Rearranging the order in which the trains depart can increase the lateness cost of some trains and reduce the lateness cost of others. However, the train sequence that minimises the total cost of lateness across all trains may not benefit each individual train. We need to determine a fair redistribution of the overall benefit.

The problem can be formulated as a cooperative game. We consider all possible ways that train operators may choose to rearrange the sequence of trains, from which we can calculate the value of every possible coalition of train operators and hence the set of fair payoffs for changing to a new optimal sequence.

Keywords: *Train scheduling, cooperative game theory.*

Choosing Efficient Hubs and Routes in an Innovative Public Transport System

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Abstract: We examine two problems that arise during the design phase of a new public transport system. The new system is characterised by the use of fixed schedule buses only between selected "hub" nodes, and taxis acting as shuttle services to and from these hub nodes.

The first problem examined is the selection of hub nodes. Hub nodes must balance the time required for mode change (if the source or destination node is not the hub node) with the cost of travel from the local bus stop to the hub node, which must be satisfied using a taxi.

We propose solving the problem as a p-Median problem. In the p-Median problem, p nodes are identified as cluster centres, and all other nodes are assigned to their closest centres. The objective is to choose cluster centres so that the sum of distances from all nodes to their closest centre is minimised. We use a modified distance function that reflects the travel cost plus the cost of changing modes (from bus to taxi and vice-versa) for all journeys in our origin/destination data.

The other problem that arises in this context is the design of bus routes between the hubs. These routes must minimise the cost of supplying buses to satisfy a given headway (time) between buses. In the results presented, we aim for a headway of ten minutes between scheduled services.

The selection of bus routes proved to be non-trivial. Many alternative routes exist, which trade off cost, number of transfers required, and travel time. A mixed integer linear programming formulation of the problem was developed and used. We present the formulation used, and one of the alternatives that were tested. The formulation rewards direct service for the greatest number of passengers, with greater reward for shorter travel time. A cost term reflects the cost of running the service, in terms of the number of buses that would be required to achieve a given frequency.

We explored route design for varying numbers of hub nodes, and for various trade-offs with respect to cost and convenience.

The proposed hubs and routes were tested using a simulation system. We were able to use actual travel data collected over four weekends in Canberra as the base demand data. This simulation confirmed that a solution with a small number of hubs gave best performance.

The results of the simulation were encouraging. The results indicate that the proposed system will be able to significantly reduce travel times and increase convenience for passengers, while at the same time costing no more that the existing fixed scheduled system. More details on the proposed system, plus results of the the simulation tests are given in a companion paper by the same authors: *Simulation of an Innovative Public Transport System* to be presented at MODSIM 2013.

Keywords: *Public Transport, P-median, Bus route design*

An Extended Demand Responsive Connector

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Abstract: Whilst the need for viable public transit systems has been well documented for decades, an exciting new de-velopment has been the formation of so-called flexible transport systems. Such services offer great potential for increases in convenience, and decreases in travel times and operating costs. One such scheme is the so called "Extended Demand Responsive Connector", which involves transporting commuters from residential addresses, to transit hubs via a shuttle service, where they can continue their journey (possibly to the CBD). To access this service, the customer and service provider decide (through some process) an earliest time the cus-tomer must be available for pick up, and the latest time they will arrive at the CBD. This paper investigates the resulting vehicle scheduling problem under a range of different parameters. Previous work has only considered *regional systems*, where vehicles had to drop passengers off at a predetermined station - our contribution is to relax this (provided timing constraints are met), and quantify this new flexibility.

This paper uses a simple nearest neighbour construction method, combined with Variable Neighbourhood Search (VNS), to quickly find solutions of a reasonable quality. We also took measures to combine the number of passengers in sparse timetables. We find that our more flexible system can offer competitive advantages over regional systems, especially when there is a higher number of transit services or stations. Finally, we show that such a system can operate with only a modest increase to the travel time of passengers (compared to a ideal minimum), offering hope that such a scheme could work in practice.

Keywords: *Flexible transportation, Demand Responsive Connector, heuristics*

Optimising Reclaimer Schedules

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Abstract: The Hunter Valley Coal Chain (HVCC), with 40 coal mines, 30 load points, 3 coal loading terminals (9 ship berths and 7 loaders), and loading about 1,500 ships annually, is one of the largest coal export operations in the world. All planning and scheduling of coal exports in the Hunter Valley is managed by the Hunter Valley Coal Chain Coordinator Limited (HVCCC) with a main goal of maximizing the throughput. Effective management of the stockyards at the coal terminals is critical to achieving this goal. Coal arrives at a coal terminal by train. The coal is dumped and stacked to form stockpiles. Coal brands are a blended product, with coal from different mines having different characteristics "mixed" in a stockpile to meet the specifications of the customer. Once the ship for which the coal is destined arrives at a berth at the terminal, the coal is reclaimed and loaded onto the ship. The ship then transports the coal to its destination. The efficiency of a stockyard depends heavily on the reclaimers' productivity. Thus, effective scheduling of the reclaimers is of crucial importance.

To better understand the fundamental difficulties of reclaimer scheduling, we are investigating a number of variants of an abstract reclaimer scheduling problem. In this paper, we consider a variant in which two reclaimers serve two parallel identical stock pads, i.e., the reclaimers move back and forth along the length of the pads and reclaim stockpiles from both pads. However, since the two reclaimers move on the same rails they cannot pass each other. The goal is to reclaim a set of stockpiles with given positions on the pads as quickly as possible.

More specifically, one reclaimer starts at one end of the stock pads and the other reclaimer starts at the other end of the stock pads. After reclaiming the stockpiles, the reclaimers need to return to their original position. The reclaimers are identical and thus have the same reclaim speed and the same travel speed. The reclaimers cannot pass each other. A set of stockpiles positioned on the two stock pads has to be reclaimed. Each stockpile has a start and end position and thus a length. When a stockpile is reclaimed, it has to be traversed along its entire length by one of the reclaimers, either from left to right or from right to left. The reclaim time of a stockpile is determined by its length and the reclaim speed of the reclaimers. The goal is to reclaim the stockpiles and minimise the maximum of the return time of two reclaimers to their original positions.

In Angelelli et al. (2013), we have shown that this variant of the reclaimer scheduling problem is NP-complete and have introduced three approximation algorithms for its solution. The three approximation algorithms use different rules for deciding which stockpiles are to be served by each of the reclaimers, but in all three algorithms the reclaimers employ a simple out-and-back routing strategy to reclaim their assigned stockpiles. To decide on the assignment of stockpiles to reclaimers, the three algorithms divide each of the pads into two parts and assign the stockpiles on left of the dividing point to the left reclaimer and the remaining stockpiles to right reclaimer. The algorithms differ in how the dividing points are chosen.

In this paper, we discuss the results of a computational study in which the performance of implementations of the different approximation algorithms are compared on randomly generated instances. The results demonstrate that high-quality solutions can be obtained efficiently for instances with widely varying characteristics.

Keywords: *Stockyard management, scheduling, routing, approximation algorithm*

Constructing Water Tank Delivery Schedules through Combined Vehicle Routing and Packing Decisions

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Abstract: This paper describes a decision-support system that was developed in 2011 and is currently in production use. The purpose of the system is to assist planners in constructing delivery schedules of water tanks to often remote areas in Australia. A delivery schedule consists of a number of delivery trips by trucks. An optimal delivery schedule minimises cost to deliver a given total sales value of delivered products. To construct an optimal delivery schedule, trucks need to be optimally packed with water tanks and accessories to be delivered to a set of delivery locations. This packing problem, which involves many packing and loading constraints, is intertwined with the transport problem of minimising distance travelled by road.

We have reviewed relevant literature on vehicle routing problems and on packing and cutting problems. Many of the problems studies in the literature have some similarities with the problem we had to solve, but none of these consider the same business rules and constraints we had to consider.

Therefore, we have combined several algorithms in a software system to assist planners of a water tank production company to construct good delivery schedules of ordered water tanks on an on-going basis. Algorithms used include: a clustering algorithm to cluster delivery locations and agent locations as a basis for constructing good delivery trips, i.e. trips with an acceptable transport cost / delivered value ratio; an adapted vehicle routing algorithm to calculate approximately optimal (shortest) delivery trips around a given intermediate storage/unbundling location; an algorithm to calculate shortest distances between geographical locations in a road network; a custom algorithm to load trucks with water tanks according to bundling possibilities; a 2D packing algorithm to load products that cannot be bundled on remaining open space on trucks and trailers; algorithms for constructing vertical and pyramid stacks of products, where products can be stacked. In addition, we have used a geolocation service to obtain geographical coordinates corresponding to delivery and agent addresses.

Each of the algorithms used solves a well-defined problem which is a part of the business problem to be solved. The main challenge was that the complete business problem is not well-defined, as business rules and constraints that have to be taken into account are often implicit; for example, a solution that might be optimal in a static sense, for delivering a given set of orders, is not necessarily optimal in a dynamic sense, for optimising business operations on an on-going basis. To obtain good solutions, not only does each of the algorithms used need to perform well, but their partial results need to be combined to produce acceptable overall solutions.

Keywords: *Optimisation, clustering, vehicle routing, packing, shortest path.*

Operational Modelling of Livestock Logistics for Simulation based Case Studies

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Abstract: Northern Australia carries about 30 percent of the nation's cattle stock and produces 90 percent of Australia's live cattle exports. The bulk of the cattle are sold from northern breeding regions to southern and south eastern feedlots and fattening properties, where they are further moved onward for live export or to slaughter. Due to the vastness of the region, the northern Australian beef industry's on-shore supply chains have very long transport distances and therefore a substantial transport cost often exceeding A$150/head (Economic Associates 2010).

This paper presents the operational modelling of the northern beef cattle livestock logistics through real time simulation models. The operational model captures the cattle movements of individual transport vehicles between enterprises, particularly between properties, holding yards, abattoirs, ports and rail/road interfaces. It accommodates various design features of individual ports and holding yards, vehicle and yard capacities, loading/unloading times, queue times, etc.

Two simulation models were developed for case studies. The first case study investigated the beef cattle supply logistics to an abattoir in the Brisbane region, with focus on the cost effectiveness of alternative transport modes, as well as the likely impact on logistic systems if the production capacity is increased. The second case study looked at the livestock cattle export logistics in Townsville Port, focusing on the coordination among different types transport modes (truck, train, and ship) and the utilisation of logistics facilities (holding yards, cattle truck fleet, and loading/unloading facilities). Finally, experimental results on port utilisation in the Townsville Port case study were tabled and discussed to demonstrate the 'what-if' scenario analyses with the simulation models.

Keywords: *livestock logistics, operational modelling, supply chain modelling, transport system simulation*

In-train forces from energy-efficient driving strategies

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Abstract: For many years the Scheduling and Control Group at the University of South Australia has been developing systems that provide driving advice to train drivers to help them stay on time and minimise energy use. These control strategies minimise the mechanical work done by the traction system, which in practice gives savings of 10–20% in the diesel fuel or electrical energy used to power the train.

These energy-efficient driving strategies require the driver to switch between maximum power and coasting and between coasting and braking. On long, heavy trains, control transitions combined with changes of gradient can cause the connections between wagons to change between tension and compression. In extreme cases, the forces between wagons can be high enough to break a coupler. Although energy-efficient driving is designed to minimise total energy input it is still possible that excess energy will contribute to unacceptable in-train forces at some critical locations.

In this paper we describe different models that can be used to estimate in-train forces on long trains, and we use the most realistic of these models to show that control transitions that may occur with energy-efficient driving do not result in excessive in-train forces.

Keywords: Energy-efficient driving, optimal control, in-train forces.

Modelling and simulation of seasonal rainfall

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Abstract: We propose and justify a model for seasonal rainfall using a copula of maximum entropy to model the joint distribution and using gamma distributions to model the marginal monthly rainfalls. The model allows correlation between individual months and thereby enables a much improved model for seasonal variation. A central theme is the principle of maximum entropy which we use to find the most parsimonious representation for the underlying distributions—using the minimum possible number of parameters to model the relevant physical characteristics. A particular emphasis is the use of the gamma distribution to model the marginal monthly rainfalls.

We wish to simulate monthly and seasonal rainfall at Kempsey, NSW during February–March–April. Our first task is to explain why we choose to model monthly rainfall totals using the gamma distribution. The principle of maximum entropy (Jaynes, 1957a, 1957b) states that, subject to precisely stated prior data, the probability distribution which best represents the current state of knowledge is the one with largest entropy. We will use this principle to argue that the gamma distribution is the best distribution to represent monthly rainfall totals provided the means of the observed monthly totals and the natural logarithm of the observed monthly totals are both well-defined and finite. This is true if the observed totals are always strictly positive. Our second task is to devise a graphical representation that displays the gamma distribution in the simplest possible way—as a straight line. We will use this procedure to compare simulated data from the chosen gamma distribution to the observed data. Our third task is to use the simple graphical representation above to compare the observed monthly rainfall to simulated monthly rainfall generated by the chosen gamma distribution. Our conclusion will be that there is no significant statistical difference between the simulated data and the observed data. Our fourth task is to to demonstrate the *goodness-of-fit* for the observed monthly rainfall data to the selected gamma distributions for each month. To do this we used two kinds of Q-Q plot. Firstly we plot simulated quantiles from the gamma distribution against theoretical quantiles to determine 95% confidence intervals and then plot observed quantiles against theoretical quantiles.

Once it has been decided that the monthly rainfall X_i can be modelled by a gamma distribution $X_i \sim \Gamma(\alpha_i, \beta_i)$ with $F_i(x) = F_{\alpha_i,\beta_i}(x)$ then the observed data set $\{x_{i,j}\}_{j=1,2,\dots,N}$ can be transformed into a corresponding data set $\{u_{i,j} = F_i(x_{i,j})\}_{j=1,2,\dots,N}$ for each $i = 1, 2, \dots, m$. This has the effect of removing seasonal factors from the observed data and also preparing for the use of a copula of maximum entropy to model the joint distribution of the monthly rainfall totals. The next step in the modelling process is to construct a joint probability distribution for the entire three-month time period. Past studies of rainfall accumulations over several months (Katz and Parlange, 1998; Rosenberg et al., 2004; Withers and Nadarajah, 2011) have observed that for models with independent marginal distributions the seasonal variance is often too low. It has been suggested that this happens because there is an overall positive correlation between the individual monthly totals. Since the observed data shows positive correlation for February-March-April at Kempsey our aim will be to construct a joint distribution so that the desired marginal distributions are preserved and so that the grade correlation coefficients match the observed rank correlation coefficients. We construct the joint distribution using a checkerboard copula of maximum entropy (Piantadosi et al., 2012a, 2012b).

Finally we compared the observed rainfall to rainfall generated by three different models (a) a maximum likelihood gamma distribution that models seasonal rainfall but does not generate individual monthly rainfalls. (b) a checkerboard copula of maximum entropy with marginal gamma distributions that preserves the observed rank correlation coefficients and (c) a joint distribution with independent marginal gamma distributions. We conclude that the copula of maximum entropy provides an excellent model for rainfall simulation.

Keywords: *Rainfall modelling and simulation, maximum entropy, gamma distribution, checkerboard copula.*

Can we trust depth-averaged models for hillslope seepage area prediction?

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Abstract: Hillslope seepage areas play a critical role in many hydrology and hydrology-related processes such as land-atmosphere exchanges, flood intensity, erosion, wetlands and riparian areas occurrence. In order to simulate these saturated areas in large catchments, the use of digital elevation models together with a depth-averaged representation of subsurface flow (the classical Dupuit assumption) has become a standard. However, the validity and limitations of the Dupuit assumption in this context are still under debate. In this work, a Dupuit-based model is compared to exact numerical simulations of subsurface flow accounting for both horizontal and vertical components. The study is carried out on a generic two-dimensional (cross-section) hillslope in which the base as well as both uphill and downhill vertical boundaries is set impervious (**Figure 1**). This setting sketches one half of an ideally symmetrical first-order catchment with no groundwater leakage. A hypothetical river, whose geometric dimensions are neglected, is assumed to evacuate both direct runoff and groundwater discharge at the valley bottom. The comparison focuses on the seepage length L_S [L] and is carried out for an extensive set of parameters values, covering several orders of magnitudes of dimensionless depth-to-length ratios d/L, hydraulic conductivity-to-recharge ratios K/R and topographical slopes s.

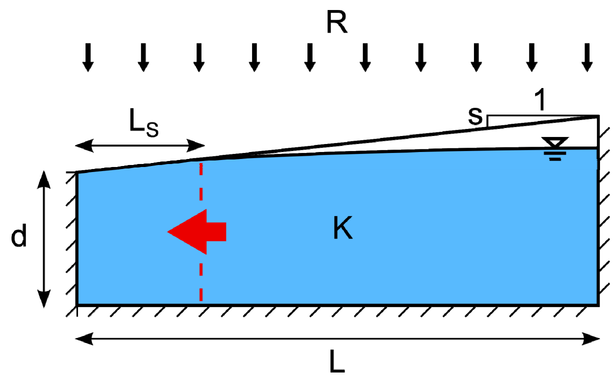

Figure 1. Generic hillslope cross-section considered in this study. The red dashed line indicates where the depth-averaging of subsurface flow (Dupuit assumption) is used.

The results reveal that the validity of the Dupuit-based model depends not only on d/L but also on the other parameters of the system (K/R, s). In fact, it is shown that the validity of the Dupuit-based model depends on the ratio of depth to seepage length d/L_S. This result finds the following geometrical explanation. Beyond a certain value of d/L_S, the vertical line at which the Dupuit assumption is used (red dashed line in **Figure 1**) becomes relatively close to the impervious downhill boundary, where the flow is forced upward. This implies a vertical component to the flow field that invalidates the Dupuit assumption. An equivalent situation can occur uphill if the vertical line at which the Dupuit assumption is used becomes relatively close to the impervious uphill boundary. As a rule of thumb, a general validity criterion can be established: the seepage length L_S [L] predicted by a Dupuit-based model is valid as long as $2d_0 < L_S < L - 2d_L$, where d_0 [L] and d_L [L] are the depths to impervious base respectively at the lowest point and at the highest point of the hillslope and L [L] is the hillslope length. This result has important implications for the sound development and use of simplified physically-based models for the purpose of seepage area prediction.

Keywords: *Seepage area, Saturated area, Dupuit assumption*

Linear Programming and the Australian Electricity Market

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Abstract: Since the deregulation in early 1990s the Australian electricity market has operated under a special competitive structure. One core element of this structure is the dispatch problem which consists of a linear programming problem that determines the dispatch price based on the bids offered by generators in every five-minute interval. Thus an optimal dual variable value corresponding to the demand constraint, the so-called "shadow price" plays a key role in determining the spot price. The underlying rationale for the use of this model is that generators will compete and, in the process, reduce the total cost to consumers.

However, the above is only a behavioural assumption. Mathematically, the shape of the feasible region of the linear program that is being solved is influenced by "parameters" that are the volumes and prices of the generators' bids. Thus, optimal basic feasible solutions and, consequently, the shadow prices are also influenced by these parameters. Hence, in principle, it may also be possible for generators to, at least indirectly, influence the spot price of electricity. Certainly, for different configurations of the bid parameters, different shadow prices of the demand constraints may result.

Indeed, we will demonstrate that in some "peak" periods the assumption that the generators are competing to lower the total cost to consumers appears to be violated and that alternative behavioural assumptions may better explain some aspects of the observed bidding strategies. We will also discuss some modifications to the dispatch model that might make it more resilient to bidding strategies of generators.

Keywords: *Australian electricity market, Linear Programming, Shadow price*

Multivariate analysis-based modelling for selected environmental and resource problems in the Adelaide and Mount Lofty Ranges area

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Abstract: With an increasing advancement of computing technology, and the desire to represent more details of physical processes, many complex models have been developed. However, applications of such complex models are sometimes not successful, owing to problems such as a lack of sufficient data, numerical instability, constraints of computing resources, and sometimes limited understanding of the model. These problems are usually not an issue when applying simple empirical models, but these can be criticized for their inability to represent all physical processes. In this presentation, we will demonstrate how simple multivariate analysis-based models can be constructed and used to solve environmental and resource problems, and understand associated physical processes, in the Adelaide and Mount Lofty Ranges. The methods used in these studies include multiple linear regression, principal component analysis, and multi-resolution analysis. The results have been published in several peer-review journal papers.

A group of multiple regression models focusing on spatial distribution of climatic variables are derived from a model (original acronym ASOADeK) developed in 2005 (Guan et al. 2005, *Journal of Hydrometeorology*) to examine orographic precipitation. The model is now called 'Precipitation Characterisation with Auto-Searched Orographic and Atmospheric effects' (PCASOA).

$$M = b_0 + b_1 X + b_2 Y + b_3 Z + b_4 \beta \cos\alpha + b_5 \beta \sin\alpha + \varepsilon \tag{1}$$

where M is the target climate variable (e.g., precipitation), X and Y are geographic coordinates, Z is terrain elevation, β is the slope angle, α is the terrain aspect, and ε is the regression error. The model only requests point measurements and a topographic map (DEM). The major innovation of this model is to use two trigonometric terms to auto-search the effect of terrain aspect on spatial distribution of climatic variables in mountainous terrains. The model can be used to auto-search prevailing climatic moisture flux direction (Guan et al 2009a, *Journal of International Climatology*) as well as other orographic and atmospheric effects on precipitation climate in mountain terrains. In addition to precipitation characterisation, the model is demonstrated useful to spatially characterize precipitation-associated variables, such as rain water stable isotopes (Guan et al. 2009b, *Journal of Hydrology*) and chloride deposition (Guan et al. 2010, *Hydrology and Earth System Sciences*), and other climate variables such as air temperature (Guan et al. 2013a, *Journal of Hydrometeorology*).

A newly developed multiple regression model incorporating wavelet-based multi-resolution analysis is used for temporal analysis of climatic variables. The advantage of this method comes from its capacity to examine relationships between the target variable and potential explanatory variables at different time scales, with the interdependency effects between explanatory variables being removed. The model has been applied in studying climatic teleconnections (He and Guan, in press, *Water Resources Research*) and in seasonal precipitation forecasting (He et al. 2013, *International Journal of Climatology*).

We have used regression-based models to spatially downscale climatic variables (Guan et al. 2009c, *Journal of Hydrology*) and to reveal temperature-dependent daily electricity consumption based on monthly electricity data. Recently, we applied principal component analysis to separate hydrochemical effects from different physical processes. The method is found useful to examine the effect of vegetation cover changes on groundwater chemistry, and to provide necessary information to apply the chloride mass balance (CMB) method for groundwater recharge estimation even under the situation where the catchment has not reached chloride equilibrium (Guan et al. 2013b, *Water Resources Research*).

Keywords: *Multiple linear regression, principal component analysis, wavelet transform, precipitation, temperature, teleconnections, water isotopes, chloride, groundwater recharge, seasonal forecasting*

Simulation of regional CSG groundwater impacts – Errors Upscaling & Multi-Phase Flow

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Abstract: Coalbed methane (CBM) or Coal Seam Gas (CSG) is considered a valuable energy resource worldwide. To produce the gas that is adsorbed to the coalbeds, groundwater is withdrawn from the coal. The associated depressurisation of the coalbeds raises concerns about impacts on adjacent aquifer systems which are an important water resource for the agricultural sector and surface water systems. Typical tools for assessing regional CSG groundwater impacts include analytical and numerical groundwater models that assume single-phase flow and static, up-scaled hydraulic properties. The up-scaled hydraulic properties are a crucial element of these models as these embody the hydraulic properties of coalbeds and the hydraulic connection between coalbeds and adjacent aquifer systems. These properties are highly uncertain due to the relative small amount of publically available data, the complex geology of the coalbeds, confining units and faults. To take in account near well-field processes like coalbed desaturation, current efforts aim to combine traditional groundwater simulation tools with CSG reservoir models. To develop new models for regional cumulative groundwater impact assessment, it is still unclear how to combine CSG reservoir models with standard groundwater modelling tools. Due to the scale of regional impact assessment and the need to evaluate a wide range of possible hydraulic properties, it is unlikely to avoid up-scaling due to computational constraints and parameterisation issues. The presented research aims 1) to quantify and compensate for modelling errors incurred by up-scaling and neglecting dual-phase flow and 2) to describe the physical resemblance of parameters in up-scaled CSG groundwater impact models. To address the above questions results a number of semi-synthetic reservoir models and groundwater models are developed. These results help determine how fine-scale reservoir simulations can be integrated into regional groundwater model design to improve the assessment of risks to regional aquifer systems posed by CSG developments.

Keywords: *Coal Seam Gas, Up-scaling, Multi-phase Flow, Reservoir Model, Groundwater Model, ECLIPSE, MODFLOW-USG*

Ocean Modelling both in Practice and in the Classroom

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Abstract: In the last decades ocean modelling has become a primary tool for environmental impact assessments and marine ecosystem investigation. Ocean modelling also plays a fundamental role in climate forecasting systems. The study of oceanic processes is a complex task and conventionally requires a high level of knowledge of analytical mathematics which, unfortunately, is outside the interests of many mainstream science students. To this end, ocean modelling (or, in other words, the numerical simulation of geophysical fluid dynamics) is rarely taught at undergraduate level of science/engineering courses of universities. This presentation has two parts. First, I will provide an overview of new teaching methods that I have developed to educate students in ocean modelling - both as part of my teaching duties and as a learning resource for the international community. To this end, I have written two interactive textbooks (Ocean Modelling for Beginners, Advanced Ocean Modelling, published at Springer) that gradually build up state-of-the-art ocean models from relatively basic single-layer shallow-water-equation models to advanced three-dimensional nonhydrostatic circulation models. The main objective of this approach is to provide students with the means to independently study and visualize complex physical processes without the need to have advanced mathematical skills. This teaching material is fully based on freely available open-source software suites, which makes it highly suitable for developing teaching environments. In the second part of my presentation, I will show research examples of key regional modelling studies that I have undertaken in recent years. This includes a study of the oceanography and flushing characteristics of South Australian gulfs providing expert advice to decision-makers as to which regions are more vulnerable to pollution exposure than others. These studies, for example, highlight that the upper reaches of Spencer Gulf are physically most unconnected to oceanic influences and, hence, most sensitive to pollution. Unfortunately, the current South Australian Government targets the Upper Spencer Gulf as "heavy industry hub" and main export corridor for future mining products, which will have negative consequences for the marine ecology of this region. I will also briefly showcase my work on the dynamics of the Great South Australian Coastal Upwelling System, which is situated in a region currently targeted by oil/petroleum companies for economic developments. This upwelling system is one of Australia's ecological hot spots of regional, national and international significance. While the existence of this upwelling system has been known for a decade, the level of marine protection of this important marine region remained insufficient.

Keywords: *Ocean modelling, New education methods, South Australian research highlights*

Evaluation of modelled and measured evaporation from a bare Vertosol soil in south east Queensland, Australia

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Abstract: Soil evaporation is often the largest component of the soil water balance in farming systems across south east Queensland, Australia. Any errors in modelling this component will have significant flow-on effects on modelled estimates of other components such as transpiration, runoff and deep drainage. Parameterization of soil evaporation in models is still, at times, an intuitive and experience based process. Recent lysimeter studies measured bare soil evaporation for a range of Queensland soils and have provided a considerable dataset with which to validate soil water balance models and improve confidence in the parameters used.

Here we evaluate soil evaporation estimated by the HowLeaky soil water balance model against measured soil evaporation during 2010 to 2012 for a Black Vertosol soil. The HowLeaky model uses two parameters, *U* and *C* (CONA), to specify soil evaporation. *U* (stage 1 drying) is the amount of cumulative evaporation since soil wetting before soil supply becomes limiting and *C* (stage 2 drying) is the subsequent soil evaporation as a fraction of the square root of time since the end of *U*. A range of commonly used *U* values, 2 to 7.5, and *C* values, 3 to 5.6, were evaluated.

The modelled soil evaporation trends agreed well with the measured trends when *U* and *C* values were adjusted. The cumulative percent difference between the measured and the modelled soil evaporation at various time points suggested that the model generally underestimated soil evaporation. However, use of the model with low *U* value of 2 and high *C* value of 5.6 gave a better approximation of soil evaporation rates than higher *U* and lower *C* values. Seasonal difference in the modelled and measured soil evaporation was apparent due to use of only one set of *U* and *C* values by the model across the seasons. However, the cumulative difference between measured and modelled soil evaporation decreased over longer time frames (i.e. 3 years) suggesting that the model is reasonable at predicting long-term soil evaporation. Prediction of soil evaporation on shorter time frames (seasonal or yearly) would be improved by using season specific *U* and *C* values in the model. The study highlights the importance of utilizing measured data for improved predictions by the model. The findings have broader applicability to models that apply the Ritchie's algorithm in predicting the soil evaporation components of water balance.

Keywords: *Clay, HowLeaky model, lysimeter, soil water balance, validation*

The challenges and opportunities of constructing Input-Output frameworks in a Virtual Laboratory – the new NeCTAR Industrial Ecology Lab

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Abstract: A Virtual Laboratory (VL) is a novel concept aimed at connecting researchers to research facilities, data repositories and computational tools on a national scale. The Industrial Ecology Lab (IE Lab) is a VL that targets a well-described, significant research challenge: the compilation and use of a time series of Australian sub-national Multi-Regional Input-Output (MRIO) tables.

IO tables describe the economic flows of goods and services from one sector of an economy to another. Modern computing power has allowed the creation of international MRIO tables that trace circuitous supply routes through the complex economic systems of the globe. These previous MRIO tables have yielded information about global trade-offs between environmental and economic objectives, and thus guide policy decisions on global matters like differentiating responsibilities for greenhouse gas emissions via consumption based environmental accounting (see Wiedmann (2009) for more information).

Rather than tracing the flows of goods between countries, the IE Lab has disaggregated the Australian economy into 2,214 regions according to the Australian Bureaus of Statistics' Statistical Area Level 2 (SA2) classification, each with 1,284 individual sectors, according to the Australian Bureaus of Statistics' Input–Output Product Classification. Australian-international trade is accounted for by an additional 'rest of the world' region.

The IE Lab is currently producing a 15 year long time series of MRIO tables allowing for economic, environmental and social analysis at a detail and breadth not before obtainable for Australia.

In this paper we discuss the construction and operational methodology of IE Lab, along with the challenges and opportunities associated with virtual cloud-based research. We present examples how the IE Lab supports the rapid expansion of national research efforts required to address the challenges of economic development occurring in the face of social and environmental constraints that are growing in number and in urgency.

With the completed IE Lab nearing full deployment, this attempt at online collaboration across Australia can be considered a success. A number of researchers are now using IO tables generated from the IE Lab for various purposes, for example in studies on future biofuel industries for Australia and on industrial symbiosis and material efficiency. The IE Lab is also collaborating with the Jolliet Lab at the School of Public Health of the University of Michigan, on modelling the environmental health effects of Australian consumption by combining an economic MRIO model with a multi-scale fate and exposure model of pollution. Further applications on the embodied carbon emissions of the built environment are in preparation.

Within this project the challenges of online (wiki style) collaboration, the mass automation of data capture and processing, and cloud-based infrastructure development and deployment have been overcome. These challenges are worth noting when discussing the creation of future Virtual Laboratories. A notable future challenge is the integration of new (second and third generation) users and data sets into the IE Lab.

Wiedmann, T. (2009). "A review of recent multi-region input–output models used for consumption-based emission and resource accounting." Ecological Economics **69**(2): 211-222.

Acknowledgments

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Keywords: *Cloud computing, Industrial Ecology, Input-Output Analysis, Virtual Laboratory, Australia*

The development of a Bayesian Belief Network as a decision support tool in feral camel removal operations

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Abstract: The removal of feral camels in Australia is complicated by the vast area over which they range, their remoteness and the changing weather conditions that constantly affect their distribution. Decision Support Systems (DSS) provide a framework in which program managers can undertake a more formal assessment of pest removal actions under different conditions, using past data and expert knowledge. The objective of a DSS in pest management is to minimise costs and optimise on-ground effectiveness. In this study we develop a Bayesian Belief Network (BBN) as a component of a camel DSS. BBNs provide a transparent visualisation of the components of the problem, underpinned by probability tables consisting of likelihoods and states in an uncertain environment. They enable managers to interrogate different scenarios, often consisting of incomplete intelligence data, and help seek the best course of action. We describe a novel approach of eliciting data from past camel culling operations into a BBN using a simulation algorithm. The algorithm simulates all aspects of the operation including search patterns, sightability, the time it takes to undertake the operation, fuel costs and camel densities. We verified the output of a range of scenarios from these simulations interactively with a group of experts and then using a wide range of environmental conditions we populated the states and dependencies of the final BBN. Using some hypothetical scenarios we demonstrate the BBN outputs including probabilities associated with a different number of camels removed and the associated costs.

Keywords: *Bayesian Belief Network (BBN), Feral camel removal, Decision Support System (DSS), knowledge elicitation.*

Role of thermodynamic sorption models in radionuclide transport simulations

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Abstract: One of the challenges in environmental contaminant modeling is simulating the interactions between dissolved contaminants and mineral surfaces, often referred to as "sorption" processes. In some contexts, such as radioactive waste disposal, it is necessary to make predictions applicable to migration over long flowpaths and geological timescales, during which the geochemistry of the disposal system may exhibit spatial and temporal variations. The key process of radionuclide sorption is often modeled using distribution coefficients (K_d values) which are typically laboratory-derived parameters dependent on experimental conditions. A number of K_d databases intended for nuclear waste applications have been compiled. While these compilations are useful for demonstrating the range of K_d for a specific radionuclide and, in some cases the factors affecting the extent of sorption, the data cannot be extrapolated to a wide range of conditions. A thermodynamic sorption model (TSM) provides a more fundamental approach to surface sorption processes. TSMs are typically based on a set of surface adsorption reactions representing the uptake of contaminants on surface sites, each with an associated equilibrium constant. The basic concepts of the TSM are:

- Sorption takes place at specific coordination sites.
- Sorption reactions can be described with mass law equations.
- Surface charge results from the sorption reactions.
- The effect of surface charge can be accounted by applying a correction factor from electrical double layer theory to equilibrium constants for surface reactions.

The choice of surface reactions is critical in developing a TSM model and should preferably be guided by structural information on surface complexes, which may be obtained by spectroscopic techniques including synchrotron EXAFS (extended X-ray absorption fine structure). In principle TSMs can provide estimates of K_d for a wide range of chemical conditions, thus reducing the number of experimental K_d values. Such models also enable sensitivity and uncertainty analyses regarding the influence of geochemical conditions as well as scoping calculations to estimate the possible effect of different scenarios on K_d values. Whilst a future objective is the direct coupling of TSMs to transport codes, the utilization of TSMs to generate or support defensible K_d values is a significant interim advance in assessing future repository performance.

Keywords: *Contaminant, sorption, radionuclide migration*

Effects of temporal fluctuations on the width of the mixing zone in heterogeneous coastal aquifers

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Abstract: Coastal aquifers are typically highly heterogeneous and the flow and mixing processes are strongly influenced by permeability variations. In addition, the groundwater density is controlled by solute concentrations. Proper accounting of mixing in coastal aquifers is relevant not only in determining sustainable management policies but also in analyzing reactions that result from mixing. The width of the mixing zone in seawater intrusion problems is dependent on the interplay between physical heterogeneity and temporal variability (e.g., due to tidal fluctuations). The interaction between local scale dispersion and temporal fluctuations of the flow velocity enhances transverse dispersion. However, the effect of this interaction on the width of the mixing zone and effective dispersion coefficients in seawater intrusion problems remains unknown. The objective of this study is to quantify the effect of tidal fluctuations on the width of the mixing zone in heterogeneous coastal aquifers using a stochastic approach. Several sets of heterogeneous hydraulic conductivity realizations were generated, and for each realization, three-dimensional numerical simulations of density dependent flow and solute transport were conducted. The simulations show that heterogeneity produces an inland movement of the toe location along with a widening of the mixing zone. Temporal fluctuations have a similar effect on the seawater intrusion dynamics but the increase of the width of the mixing zone can be much larger than due to heterogeneity alone. The enhanced solute mixing is quantified by an apparent dispersion coefficient. We find that solute dispersion increases consistently with storativity because when storativity is increased fluctuations in the flow boundary conditions (tides) propagate through the aquifer with a reduced speed, which leads to a more complex time-dependent flow field. This may have important implications for the understanding of mixing and reaction processes in unconfined groundwater systems. It may also lead to biased parameter estimation in modeling studies of aquifers of which the degree of confinement is poorly constrained in the sense that if the adopted storativity values are inaccurate, the calibrated apparent dispersion coefficient may be incorrect as well. This may under- or overestimate mixing when the model is used for predictive simulation outside the range of conditions during the calibration period.

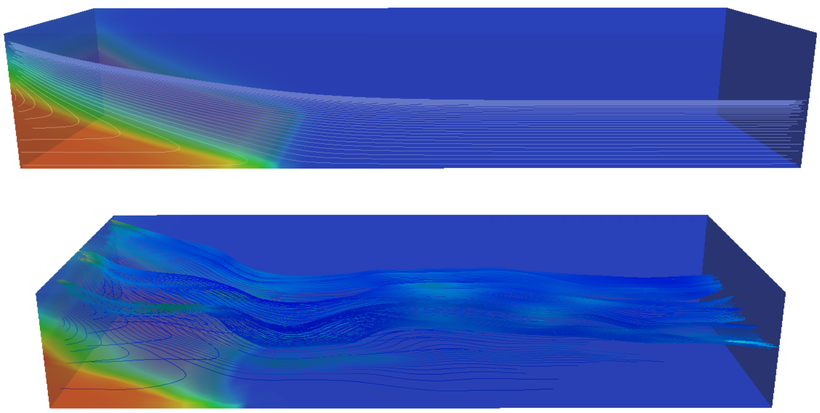

Figure 1. Concentration distributions and flow lines in a homogeneous aquifer (top) and in a heterogeneous aquifer (bottom)

Keywords: *Temporal fluctuations, mixing, seawater intrusion, heterogeneity*

Towards decision support tools for incident managers dealing with large bushfires

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Abstract: Incident Management Teams (IMTs) dealing with large bushfires operate in high pressure environments. IMTs have to make complex, time critical decisions. Factors that need to be considered include among others weather conditions, fire spread predictions, fuel state, assets under threat, the value of assets and the location of vulnerable people. The main aim of this research is the development of decision supports tools for IMTs in extreme conditions when fire fighting resources are inadequate to protect every property and when options other than active suppression must be considered.

The formulation of a model to investigate asset protection in the absence of suppression efforts with cooperating resources is presented. The model is formulated with the aim of addressing the following question: How may IMTs best utilise the available resources during large bushfires?

The problem of allocating resources during large wildfires is closely related to the team orienteering problem with time windows (TOPWT). However, the problem of allocating resources during wildfires requires the formulation of a new mixed integer programming model. The new model builds on the TOPWT by adding a protection requirement to each location. Sufficient resources must arrive at a location during the time window to enable the collection of a reward. In the model the assumption is made that all resource units, typically tankers, have identical properties and capabilities.

The model developed provides the ability for an IMT to determine the resources required during a bushfire to adequately protect all assets. The model may also be used to give an optimal resource allocation for a given set of resources and assets requiring protection. If accurate fire spread prediction is available then the model may be utilised in real time. Future work will consider extensions of the current model to allow for mixed resource types.

Keywords: *Bushfire, incident management, decision support, orienteering problem*

Using scientific workflows to calibrate an Australian land surface model (AWRA-L)

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Abstract: The AWRA-L landscape hydrology model is one of three model components which form the Australian Water Resources Assessment (AWRA) system that aims to produce interpretable water balance estimates for Australia which (as much as possible) should agree with observations such as point gauging data and satellite observations. It is a 5 km grid-scale model, driven by interpolated climate inputs, that produces continental surfaces representing water stores and fluxes across the landscape, as well as energy and vegetation dynamics at daily timestep. The system is jointly developed by CSIRO and the Bureau of Meteorology (BoM) with model improvements proposed regularly, requiring re-calibration. This regular execution makes scientific workflows an attractive solution for engaging in our large computation and data transformation tasks whilst also providing HPC scheduling, repeatability, traceability and monitoring.

Initially, various software tooling was explored to assist with the calibration of AWRA-L. These included the Catchment Water Yield Water Estimation Tool (CWYET), and various third party products such as PEST, UCODE and PGO. These tooling products were not quite suitable for use with calibrating AWRA-L largely due to the complex calibration requirements (such as the formulation of the AWRA-L objective function) and the lacking flexibility to evolve these products for future AWRA-L calibration requirements. Instead, two prototype systems were developed in Matlab: one with a targeted execution environment on a desktop; and the other with a targeted execution environment on a cluster. From these two prototypes a toolset was then developed based upon the Metaheuristics (Perraud et al, 2012) Application Programming Interface (API), which is a loosely coupled framework for assisting with model optimisation. Scientific workflow software was then used to orchestrate the flow of information between the model calibration processes.

This paper describes the process undertaken to calibrate proposed changes to AWRA-L, design objectives, and current state of the suite of workflow activities developed known as the 'AWRA Calibration Tools'. Trident workbench was used to develop automated workflows for processing including: including: parameter optimisation; model simulation; and benchmarking of results. These tools allow domain experts to execute and share workflows, enabling AWRA-L to be steered in a direction that either improves the model's predictability or is considered to have an improved physical representation without significant degradation in predictions. The paper concludes by identifying key challenges that have emerged, and suggests some improvements for the future.

Keywords: *Trident Workbench, Optimisation, Workflows, AWRA, High Performance Computing*

Real-time numerical simulation of storm surge inundation using high-performance computing for disaster management, Queensland

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Abstract: Storm surge presents the greatest hazard to life in tropical cyclone (TC) events, and the Queensland coastline has particular vulnerability to such extreme events. Presently, the Australian Bureau of Meteorology (BOM) issues warnings of forecast storm surge magnitudes using a static look-up table of scenarios associated with forecast cyclone track parameters. In association with Emergency Management Queensland (EMQ), Griffith University has initiated a research project investigating the potential to dynamically model storm surge inundation in real-time during TC events. The project aims to optimise emergency planning and evacuation strategies for storm surge impacts for impending TC landfall by providing outputs at greater spatial resolution, extension into inundation modelling over land, and development of a probabilistic approach to storm tide simulation that may provide emergency managers with a more complete view of possible outcomes.

Here we present an overview of a feasible systems approach to real-time storm surge forecasting optimised for run-time, including generation of an ensemble of forcing wind and pressure fields, a hydrodynamic model and post-processing of model output for delivery to emergency management agencies. An ensemble approach to TC forecasting suitable for storm surge modelling has been developed in order to gain an understanding of the critical effects of the spatial, temporal and intensity uncertainties in TC forecasts on the resultant storm surge forecast. Parametric wind/pressure fields for each ensemble member are generated to force the finite volume hydrodynamic model, which has been built using MIKE21 by DHI software implemented on Griffith University and project partner Queensland Cyber Infrastructure Foundations (QCIF)'s high performance computing facilities. Two versions of the hydrodynamic model have been constructed, calibrated and validated for TC storm surge: the 'nearshore' model with spatial resolution of ~1-2 km in the nearshore zone outputting discrete storm surge magnitudes, and the 'inundation model' with greater spatial resolution capable of dynamically modelling storm tide propagation over land. The output of the nearshore model would be combined with a bath-tub mapping approach to yield probabilistic storm tide inundation estimates. The inundation modelling yields storm tide depth surfaces directly, to be combined into a probabilistic surface.

A case study comparing the simulation time required to model storm tide inundation using the two approaches for TC Yasi is presented. The nearshore modelling combined with the bath-tub mapping approach yields achievable run-times for an ensemble forecast. The inundation modelling approach is currently too computationally expensive for the ensemble forecasting method developed for this study and efforts to optimise the simulation time are underway. A comparison of the resultant storm tide inundation levels obtained by each approach is in progress. Understanding these differences may lead to the development of techniques to improve the bath-tub mapping approach.

Keywords: *Storm surge, tropical cyclone, numerical modelling, high performance computing, emergency management.*

Initial Analysis of Fire Weather Characteristics between South-East Australia and South-West of Western Australia

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Abstract: Australia is a continent in which bushfires are an endemic part of the landscape. A bushfire can occur anywhere at some time of the year, restricted by the presence of flammable fuel, conducive weather conditions and an ignition source.

Due to its size, Australia spans a wide range of geological and climatological zones, resulting in a large number of unique landscapes, from arid desert to rainforest to alpine, the genesis of a number of significant differences in fire weather between the east coast and west coast of the continent.

The potential for disastrous fire is dictated by three factors that influence fire behaviour: (a) the type of vegetation (fuel) in which the fire is burning; (b) the weather; and (c) the topography in which the fire burns.

This paper centers on (b) the weather, particularly the fire danger weathers measured by the McArthur Forest Fire Danger Index (FFDI). It concentrates on the comparison of fire danger weather conditions of south-east of Australia and south-west of Western Australia.

Weather datasets since 1990 from almost all Automatic Weather Stations in Australia were acquired and 28 were selected and analysed. Furthermore, six sites were particularly chosen, one for each state/territory, for this comparison study.

A number of fire danger severity measures were developed including the number of Extreme FFDI days per fire season and the longest number of consecutive Extreme FFDI days. The paper has a number of findings including the similarities of fire weather conditions of the two regions and their differences. This initial analysis motivates us to engage further research on other important fire risk factors such as vegetation, distribution of infrastructure, properties and population at risk, and possible correlation between the past fire ignitions including disastrous fire events and FFDI.

Keywords: *Fire weather conditions, forest fire danger index, fire ecology*

Information Integration for Emergency Management: recent CSIRO case studies

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Abstract:

The CSIRO ICT Centre's Information Engineering Laboratory has been involved in a number of emergency management related projects over the last four years. In these projects we have applied our software engineering expertise in the areas of web technologies, user interfaces and databases along with research capability in machine learning, distributed systems, text processing and data stream management. This process has increased our understanding of the various roles and responsibilities of different government departments at the federal and state level and of the wider emergency services community.

The research agenda of the CSIRO is broad and its application to the area of disaster management is no different. In this field of research, one of the CSIRO's aims is to improve the process and service delivery of disaster management in Australia and to provide high-impact solutions to strengthen the disaster resilience of the nation in the future. As well as the projects reviewed in this paper, there are other research activities underway or completed within the CSIRO that address the issues of disaster management, see Hawkins et al. (2012) for an overview.

The focus of this paper is to present three recent CSIRO projects related to emergency management, highlighting their differences and similarities with a focus on the challenges encountered and a categorisation of the target data items utilised.

The Pilot Impacts Portal, `http://www.fend.org.au/`, is a web accessible user interface to a collection of national data items describing historical fire emergency and natural disaster events and their associated impacts. The project was a collaboration with Fire & Rescue NSW that aimed to better understand the economic, social and environmental impacts on communities due to disaster events.

The Emergency Response Intelligence Capability project, `http://eric.csiro.au/`, is a collaboration with the Australian Government Department of Human Services Emergency Management team who are responsible for intelligence gathering and situation reporting during emergency events. The CSIRO have developed a tool that supports the department's operational tasks by automatically gathering data from a range of sources, presenting the data on a map based website and generating customised situation reports.

The Emergency Situation Awareness system, `https://esa.csiro.au/`, analyses Twitter messages to provide early detection of emergency events. It extracts situation awareness information as the disaster unfolds, effectively crowd sourcing relevant details and providing time critical information that allows emergency services to respond rapidly and appropriately.

A short overview of each project is presented. Each system makes use of different types of information: historical archives, community details, near-real-time authoritative event information and social media content. Combining all of this information will provide emergency management organisations with better quality information for decision making resulting in improved community outcomes. Social media is a new channel of information that can provide further intelligence about emergency events. Authoritative information is being published on Twitter by the emergency services community which can be augmented with non-authoritative crowd sourced social media content to provide a better understanding of emergency events.

Keywords: *Crisis coordination, disaster management, situation awareness, social media*

Emergency Response Resource Quantification and Prioritization

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Abstract: Disruptions to critical infrastructure from natural disasters and man-made events occur on a regular basis. For large, regional events, local infrastructure providers may find that the event goes well beyond their planning basis, requiring resources that are unavailable. Moreover, allocation of scarce resources often takes place with limited understanding of how the overarching objectives in varying time frames – minimization of loss of life in the short term, maximization of public health and safety in the intermediate, and minimization of economic impact in the long run – are to be satisfied.

The National Infrastructure Simulation and Analysis Center (NISAC), a program managed by the U.S. Department of Homeland Security (DHS) and comprised of a core partnership of Sandia National Laboratories (SNL) and Los Alamos National Laboratory (LANL), performs critical infrastructure analysis, modeling, and simulation in support of the DHS mission. NISAC has worked to develop a model for quantifying and prioritizing resources for infrastructure restoration following disruptive incidents such as earthquakes and hurricanes. This model, called Infrastructure Resource Allocation and Prioritization for Incidents (IRAPI), is designed to identify available resources and requirements on those resources in a temporal fashion. The model matches these resources and requirements within appropriate time frames to meet the overarching objectives described above. This method is best used within the mitigation and preparedness phases of the emergency response lifecycle, but has been used as part of the response and recovery phases as well.

IRAPI is designed to provide users with a geographic information system (GIS)-based user interface, where an event can be described against a specified area. The underlying model draws on information solicited from an event type-specific resource priorities survey, which is used to define modeling characteristics and data requirements. An event type-specific model of resource allocation is used to pair requirements with resources to meet objectives given logistical and communications constraints. This model is a variant of the attacker-defender model, in reality more of a "random attacker-mitigator" model. In this case, the series of objectives form a sequential game featuring imperfect information, with gradually decreasing uncertainty about the true state of the world. For some event types, this random adversary could be modified into a decidedly non-random role, one that attempts to maximize the impacts given knowledge about how the system is constructed or how response is expected. Validation of relative valuations of resources for particular purposes at points in time within the model are the product of both the above-mentioned survey as well as the results of interactions of subject matter experts with an event type-specific system dynamics model of event response. As with the input, IRAPI uses a GIS interface (NISAC's FASTMap tool) to present the model results as an animated sequence of maps showing the ability (or inability) of an area of responsibility (corresponding to an area with allocation and disposition rights over resources in the event of activation of an emergency response plan, such as a county) to meet resource demands over time.

The concepts of IRAPI received a trial-by-fire test during Superstorm *Sandy* (2012), which battered the New York-New Jersey metropolitan area. Working with the State of New Jersey Office of Homeland Security and Preparedness (NJ OHSP) and the Federal Protective Security Advisor (PSA) for the State of New Jersey, NISAC used IRAPI to examine resource needs and priorities for select commercial sector asset classes, including fuel facilities, pharmacies, and food facilities. Data provided by NJ OHSP was combined with power outage and storm surge data produced by the Federal Emergency Management Agency to delineate effects to assets, and requirements for restoration. Key findings helped define actions taken by NJ OHSP for restoration of service to assets in these sectors.

This is document SAND2013-8486A.

Keywords: *Critical infrastructure, Prioritization, Resource allocation, Emergency response, National Infrastructure Simulation and Analysis Center*

A national fire behaviour knowledge base for enhanced information management and better decision making

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Abstract: Accurate prediction of bushfire behaviour is essential for effective fire management. Such knowledge allows for the timely determination of the potential threat and impacts of a fire and provides the basis for sound fire-management decision-making. Fire behaviour prediction combines quantitative and qualitative information sources that are based on scientific principles and personal experience describing the combustion and behaviour of fire in a range of weather, fuel and topographic conditions. 'Amicus', the National Fire Behaviour Knowledge Base, is a new software-based tool under development that endeavours to provide a unique framework in which each of these information sources is accessible and utilisable in a consistent and comprehensive manner for the sole purpose of operational prediction of the behaviour of bushfires by trained fire behaviour analysts.

The Amicus system comprises four primary components: fuel description, fuel moisture models, wind models and fire behaviour models and uses these to predict fire characteristics (e.g. rate of spread, flame height, fireline intensity, onset of crowning, spotting potential) for a broad range of burning conditions. This paper details the current development of the fire behaviour component of Amicus and its proposed integration with the Australian Bushfire Fuel Classification System being developed for use across all Australian jurisdictions. The fire behaviour component will integrate a suite of fire behaviour models covering the main Australian fuel types: eucalyptus forests, exotic pine plantations, grasslands and shrublands.

Further development of Amicus will integrate the fire weather, fuel dynamics, and suppression capability knowledge and science to help fire managers better predict bushfire behaviour and better plan prescribed burns.

Keywords: *Bushfire, fire spread, fire prediction, fire models, software development, Workspace, workflow*

Zero Cost Solutions of Geo-Informatics Acquisition, Collection and Production for Natural Disaster Risk Assessment

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Abstract: The global and local impacts of climate change and natural disasters cause great casualties and economic losses each year. Catastrophic events bring more damage to urban areas than rural places because of the high density of human population, property and the infrastructures. Geo-informatics is critical for all stages of disaster management including disaster prevention, preparedness, emergency decision making, disaster relief, rebuilding and recovery. It is critical for risk assessment of natural disasters.

Since all hazard risk components are location-specific and vary spatially, accurate risk assessment relies on geo-informatics. Geo-informatics as the basis of decision-making information has proved to be critical and essential to natural, technological and manmade disaster risk assessments.

Commercial sources of geo-informatics are usually expensive, especially for those developing countries and regions where living standards are low but natural disasters occur more frequently and cause large losses. The expense of geo-informatics acquisition, collection and production varies vastly with different update frequency, imagery quality, and the total amount of information carried. In contrast with commercial sources, free sources of geo-data and geo-software have limited comparable features. However, they have the flexibility to add new features by further development.

Based on a current study of urban natural disaster risk assessment and vulnerability mapping which aims at improving community safety and resilience to natural hazards, this paper shares our experience on zero cost solutions of geo-informatics acquisition, collection, and semi-automatic production procedures by using free internet resources of Google Maps, Google Earth, and free and/or open source software including QGIS (Quantum GIS), GRASS, SAGA, Monteverdi, Sextante GIS and Orfeo Toolbox. In order to enrich attributes to meet the requirements of risk assessment, methods of combining the acquired geo-informatics with other formats of geo-data (*e.g.*, Digital Elevation Model, raster layers, vector layers, and Microsoft Excel files) are introduced.

The purpose of this paper is to share our experience on zero-cost geo-informatics acquisition, collection and production solutions with urban planning managers, emergency managers, risk researchers and people with similar concerns. The geo-informatics developed from this research forms a basis for disaster vulnerability measurement which is an important part for urban disaster risk assessment.

Keywords: *Geo-informatics, GIS data acquisition, GIS data production, natural disasters*

Numerical and analytical groundwater models as validators for an agent-based empirical subsurface flow modelling scheme

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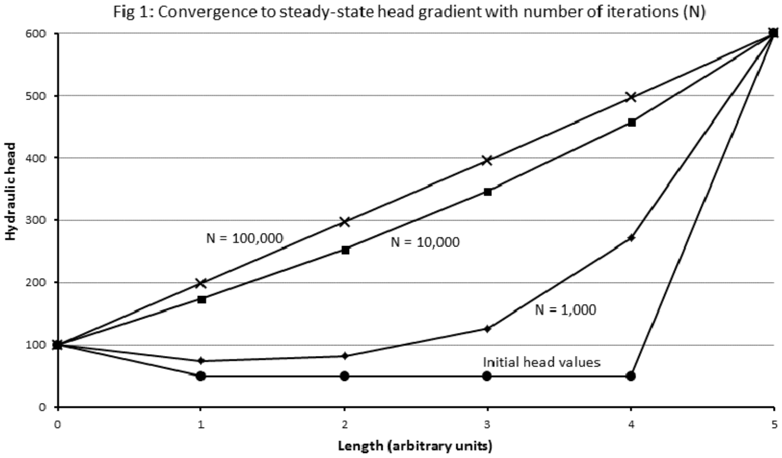
Abstract: Water resource modelers have long utilised numerical groundwater models based on local solutions to governing equations. An alternative empirical agent-based stochastic approach is suggested here for modeling Darcy flow situations. The obvious means of validation is comparison with numerical and analytical groundwater solutions for the same boundary conditions. As with Lattice Botzmann approaches, the proposed method has the nodes of a lattice populated with an initial set of "particles" which can be interpreted as agents subject to movement rules, but in this case the frequency of agents at a node represents local water pressure. Hydraulic conductivity K may vary spatially but is assumed known. A calculation is first made of KΔh (equivalent to Darcy flow speed) for all adjacent node pairs. These KΔh values are then rescaled to sum to 1.0 as a probability distribution. A single KΔh value is selected at random, with selection probability proportional to the magnitude of KΔh. A single water particle "agent" is then moved down the head gradient between the node pair selected and a pressure adjustment made for those two nodes. The probability distribution is updated and then the whole process repeated many times to a solution. This approach has the advantage that the solution process is a non-mathematical stochastic hydrological visualisation as opposed to black-box solution of systems of equations, making the modeling more amenable to explanation for teaching situations. Also, particle tracking, boundary conditions, and time-varying models are easily incorporated. The approach, though intuitive, remains at present as simply "empirical agent-based modeling" in the absence for now of a formal proof of convergence to the true solution. Fortunately, both numerical and analytical groundwater models are well established for validation checks of agent-based groundwater modeling.

Fig. 1 illustrates validation by application of the agent method to a classic steady state one-dimensional groundwater flow model, with uniform conductivity and four internal nodes. Both hydraulic head and distance are in arbitrary length units. Groundwater flows from the right fixed-head point (h=600) to the left fixed-head point (h=100). The four internal nodes were assigned h=50 as initial heads. It is evident in this case at least that the true solution (a linear head gradient) is increasingly well approximated by the agent method as the number of iterations increases. This work is only the initial stages and many more comparisons are required.

Fig 1: Convergence to steady-state head gradient with number of iterations (N)



Keywords: *Groundwater agent, stochastic model, validation, groundwater model*

How agency models inspire large scale participatory planning and its evaluation

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Abstract: We describe how three models, for sustainable change, human agency in collective resource management, and socio-environmental systems, have been used to design a protocol and the tools for a large scale (1500 participants, 35 villages) multi-level participatory process held in Africa for Integrated Natural Resource Management, through the European Project Afromaison. The process especially combines a common action model to support proposals by stakeholders, an integration matrix to build coherent plans, a role playing game design process, and a method to combine planning and playing to engage into the plans. It has also inspired the design of the attached monitoring and evaluation process. We describe the process in two countries, Ethiopia and Uganda, present the theoretical bases of the evaluation framework using the ENCORE paradigm and the implemented methodology transferred to local evaluators. We introduce some results and propose comments on potential learning back to the modelling community.

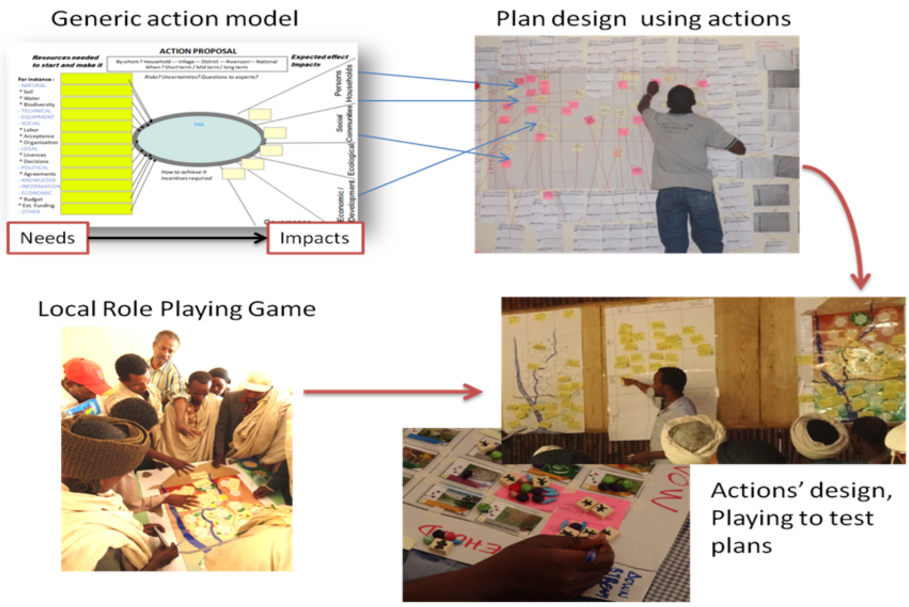

Figure 1. The main methodological tools

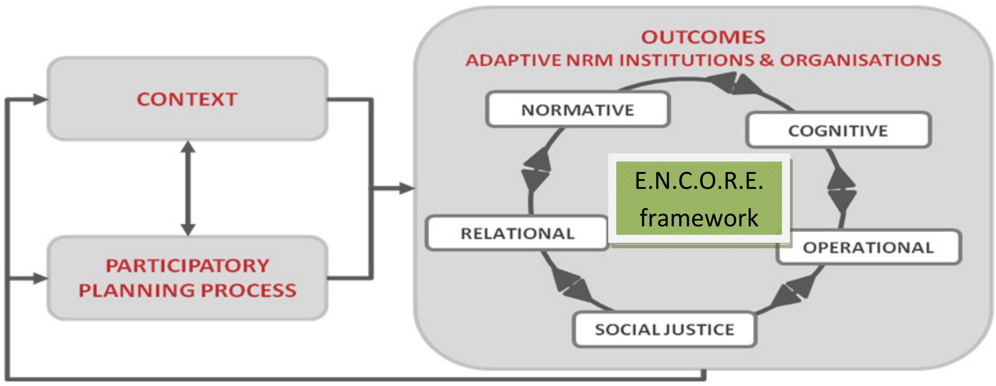

Figure 2. Theoretical Framework for the Monitoring & Evaluation process

Keywords: *Participatory planning, monitoring, evaluation, integrated natural resource management, role-playing-game, Africa, multi-level governance*

Modeling work organization in grape production to study its environmental impacts

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Abstract: In many vineyards in France, the grape production process is strongly dependent on the use of pesticides (insecticides, fungicides, herbicides) to combat various causes of yield and quality losses. These practices can potentially impact on the environment, in particular surface and ground water. Reducing this impact is an important challenge for viticulture in the coming years. While many recognize the importance of getting a deeper understanding of the environmental effect of the growers' management behaviors very little research effort has been focused on this issue. There is clearly a need to investigate the organizational constraints and difficulties of any grower to carry out his concurrent management activities in a timely, efficient and responsible manner.

In this paper we describe the model DHIVINE of a grape growing production process at vineyard scale. The focus is on how technical activities are represented and organized in flexible plans that specify also the possible resources (labor, equipment) to be used in their implementation. The originality of the approach lies in the versatility of the representation of dependencies between the activities, the state-dependant conditions of their implementation, and finally the dynamic and contextual choice process of activities, operated entities and resources allocated to the execution. Activities can be constrained individually through opening and closing conditions (calendar dates or state-related predicates) that enable elastic specification of what to do. In addition, a so-constructed plan is made flexible by the use of patterns that enable optional execution, choice between candidate activities and adjustable iteration of activities. Finally another source of flexibility supported by our management plan representation is obtained through the abstract specification of the entities to be processed by the operation underlying any primitive activity. The entities are defined in intension, that is, by rules that enable on-the-fly generation of the set of them that satisfy the rules, e.g., the 'set of vine plots' to be tilled that are specified by characteristics of the alleys (width) and by previously performed operations. The DHIVINE model relies on the generic ontology DIESE developed by the first two authors.

DHIVINE is well-adapted to the study of centralized decision-making with a focus on the timing and contextualization of activities in a highly changing environment, which is the case for any crop production system that has to cope with uncontrollable factors such as weather or pest infestations. Our modeling approach enhances traditional farm analysis instruments by providing a holistic and process-oriented view of technical operations. The simulation of management practices helps to understand the environmental consequences of chemical treatment strategies, analyze alternative policies and design innovative production processes. With this approach, the emphasis is on the explicit representation of what governs the context-dependent determination of actions consistently with management intentions, organizational constraints and decision-making preferences. Simulation provides quantitative estimates of the operational and environmental impacts that management strategies are likely to have in response to uncontrollable factors.

The paper considers an illustrative example of management strategy that represents the observed practices of a real grower in southern France. The subpart presented focuses on work schedules pertaining to soil surface interventions on each plot of the grape growing system. These schedules used as plot-dependent input of an hydrological model enable to evaluate the risk of diffuse surface water pollution by pesticides. By changing the state of the soil surface, these activities influence the volumes of runoff pollutants at the outlet of the plots. Initially the model DHIVINE is set to represent the actual structure of the farm (vineyard, material resources and labor) and the management strategy of the vineyard. Then two alternative management strategies are applied to test the impact of two changes of work organization, one concerning the priorities of the technical operations, the other concerning the resources required for each operation. The sequences of management interventions obtained by simulation reproduce faithfully the real ones observed over three successive crop cycles. The results are very sensitive to the work organization underlying each strategy, with a large variation in the number of interventions performed depending on the strategy.

Keywords: *production management, resource allocation, environmental impact, grape production*

The MASE design experience

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Abstract: In Computer science, agent-based modeling (ABM) and multi-agent simulation contribute to scenario anal-ysis, since they may represent patterns of human interaction, which are essential to a better understanding of real systems, including many different aspects such as social, economical and environmental. This paper presents the use of agent-based techniques to define and develop the MASE - Multi-Agent System for Envi-ronmental simulation model using two different design approaches: the TROPOS Agent Oriented Software Engineering methodology with JADE framework, and the Agent-Object-Relationship modeling and simulation platform. MASE model system was defined to characterize land-use change dynamics through a replicable pa-rameterization process, useful to the development of agent-based simulation frameworks. However, different agent-based design experiences can enrich the modeling and development process of environmental simulation frameworks, since they embed conceptual structure definition according to specific design concepts. Thus, in this paper we include a short discussion of challenges, perspectives and limitations of two design experiences involving different concepts and techniques for information systems analysis. We believe the reported discus-sion can serve as a starting point to define evaluation criteria for comparative analysis of different agent-based design approaches. To illustrate land-use simulations with MASE we used the Brazilian Cerrado case study.

Keywords: *Agent-based modeling, design options, process design, brazilian cerrado case*

Validating simulations of development outcomes in the Mekong region

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Abstract: The wider Mekong region is experiencing an unprecedented influx of private and foreign investment, which is transforming many areas of the six riparian countries. Most investments target access to natural resources, demoting the outcomes of development objectives such as poverty alleviation to coincidental side-effects. The Mekong region simulation (Mersim) model aims to improve the understanding of unintended side-effects, by providing the computational foundation for a participatory learning process involving decision makers and decision influencers. The model simulates the poverty and economic outcomes of scenarios selected and designed by participating decision makers, including the impact of Mekong mainstream dams, the impact of payments for ecosystem services on land use change, the impact of large scale irrigation, and the impact of sealevel rise. The complexity of these social-ecological processes emphasises the relevance of iterative participant validation. This paper describes a process that involves a pattern-based validation technique as an alternative to a numerical validation method. The patterns were introduced in structured workshops to challenge causal beliefs elicited during the participatory process and validated through facilitated stakeholder discussions. This paper explains how, as an initial response, stakeholders actively defend currently held beliefs. When confronted with the counterintuitive results and outcomes simulated by the Mersim model, the discussion shifted to understanding model mechanisms, allowing stakeholders to explore alterative beliefs and some held beliefs were readily amended, validating some important results of the Mersim model.

Keywords: *Agent-based modelling; Validation; Mekong.*

Designing a simulation-supported learning process for decision makers in the Mekong region

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Abstract: Hydropower development, expansion of rubber plantations, large scale irrigated agriculture and sea level rise represent some of the key opportunities and risks perceived by decision makers in the Mekong region. Using opportunities wisely and responding effectively to risks without compromising a sustainable future demands insights into complex system responses. This paper describes a participatory learning process for decision makers and decision influencers in five countries located in the wider Mekong region. Structured engagement processes and mixed methods address the learning challenges associated with high levels of system complexity and the values of competing interests. The mixed methods approach involved a suite of disciplinary specific models, household surveys and an agent-based simulation model. Learning was facilitated by challenging beliefs articulated by stakeholders during the participatory process. In the context of the wider Mekong region modelling was an essential element and this paper is focused on the role of agent-based modelling and its effectiveness. A key insight from this study is that the potential to introduce doubt and challenge prevailing beliefs – and thereby to facilitate learning – increases with the complexity of the particular method implemented. Overall, this work emphasises the relevance of process design to effectively address cognitive barriers encountered at the science-policy interface and achieve targeted learning outcomes.

Keywords: *Agent-based modelling; Participatory process design; Mekong*

Validating human decision making in an agent-based land-use model

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Abstract: Validation of agents' decision making is one of the central epistemological problems in empirical agent-based model (ABM) simulations. This paper focuses on the need for reliable decision-making models for land change science with direct relevance to modelling human-environmental systems for policy implications and natural resources management. This paper presents a set of key issues or caveats that affect the validation. At the same time, we present alternatives by providing examples of a more stakeholder-centric way of parameterizing human behaviour and decision making, and a case study is described in the light of critical multiplism.

Keywords: *Land-use change; validation; human decision making; stakeholder participation; critical multiplism*

EXTENDED ABSTRACT ONLY

ABM design: using empirical data to contextualise a theoretical model of cooperation in the commons

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Abstract: Agent-based modelling (ABM) can be of value to gain more understanding of the dynamics of social-ecological systems (SES), for instance, how social-ecological interactions shape cooperative resource use. SES studies typically focus on real world problems with a complex systems lens. They are, however, often restricted to either abstract models or rich descriptive case studies. We want to add another approach to SES research: ABM cases, in order to bring the rigour of analytical models and the complexity of the real word context closer to each other. The aim of this approach is to gain a systematic and mechanistic understanding of SES dynamics at an intermediate level of complexity, taking relevant aspects of the social-ecological context into account, i.e. context sensitive theories. We here illustrate the approach by presenting the process of contextualizing a theoretical model of norm-driven cooperation to the case of rice-paddy irrigation in Bali. The rice paddy farmers in Bali cooperate in their use of water to grow rice and avoid pests. This case of successful resource management has been intensively studied and generated much social and ecological data..However, performance differences between communities and factors affecting their adaptability to change are still unresolved. It has been speculated that the ability to engage in collective action is a major factor. The combination of available empirical knowledge and an open question of relevance beyond the individual case make for a relevant ABM case.

Designing an ABM with use of empirical data is not uncommon. Typically, empirical data in the design stage is used to choose and select the appropriate set of model components, as well as their respective values, and the appropriate level of details, i.e., sound micro *specification* by empirical *calibration*, see figure 1 (left). Our approach is similar as the selection of model components is also informed by the empirical data. However, the model design stage is additionally fed by two other sources: a theoretical model of norm-driven cooperation and the SES-Framework developed by Ostrom, Figure 1 (right).

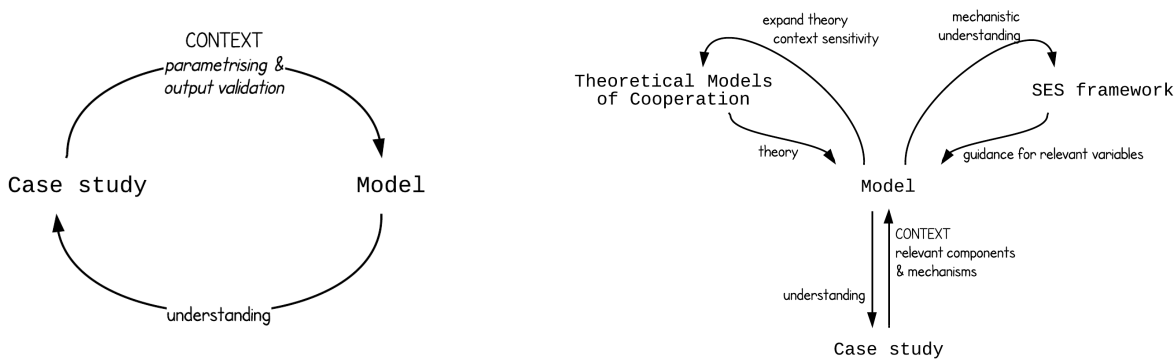

Figure 1. Left: Most common use of empirical data in the design stage of agent-based modelling (ABM). Right: Our approach where an ABM is developed from three sources: theory, case & SES framework.

This talk will focus on the process to model an ABM of Bali irrigation. We will particularly communicate the way we move a theoretical model of cooperation closer to the real world phenomena: model contextualisation. Model contextualisation concerns the inclusion of relevant contextual factors without losing the ability to generalize and systematically explore SES of the same type. We thus make one of the first modeling decisions explicit in bridging the theoretical concepts and the empirical factors of relevance using empirical data and knowledge guided by the SES framework and discuss tradeoffs in selecting contextual details and maintaining generalisability, i.e., developing context sensitive theory.

Keywords: *Agent-based case studies, contextualising models, Bali irrigation*

Optimising economic and environmental outcomes: water quality challenges in Corner Inlet Victoria

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Abstract: The Corner Inlet and Nooramunga Coastal Hotspot and Ramsar site is one of Victoria's important environmental assets. The seagrass beds are critically important to the ecosystem and these are under threat due to sediment and nutrient (nitrogen, N and phosphorus, P) export from agricultural land management (mostly dairy and beef). The West Gippsland Catchment Management Authority (CMA), along with the Victorian and Australian governments, have responsibilities balancing the needs of local communities, including the economic viability of agricultural and fishing industries, and protecting the environmental values of the site through developing and implementing a Water Quality Improvement Plan (WQIP).

This study used science and local expert knowledge to develop a bioeconomic optimisation framework (using the General Algebraic Modelling System, GAMS) which informed a stakeholder panel overseeing the WQIP about the costs of achieving pollutant reduction targets under different land use and management options. These included traditionally funded activities (gully, stream and waterway fencing), agricultural 'best-management practices' (BMPs) and land use change. A previously calibrated catchment model provided sub-catchment load estimates of total N (TN), total P (TP) and total suspended sediments (TSS). Development of a new land use layer allowed the proportions of dairy, beef and forestry to be ascribed. BMP effectiveness was assessed by expert opinion and the contribution of gully and waterways were estimated by extrapolating nearby modelling and mapping information based on similar soils. The change in operating profit was calculated assuming single representative dairy and beef systems and practices.

A stakeholder and technical panel comprising the CMA, Victorian and Australian governments, farming, fluvial ecology, hydrodynamics, seagrass ecology and catchment modelling expertise oversaw development of the WQIP. Choices about TN, TP and TSS reduction targets to be assessed were made based not only on estimated ecological outcomes, but also considering costs and political acceptability of implied land use and management changes. Three scenarios are presented: 'ideal at least cost' (best estimate of load reduction targets required to maintain seagrass); 'revised at least cost' which was half of the ideal target; 'revised with traditional activities only' (gully, stream and waterway fencing).

Achieving 'ideal' targets at least cost was estimated to result in an average loss in profit (cost) of \$458/ha over the grazed area (757 km^2) and involved large scale retirement of agricultural land (over 96% dairy area and over 30% beef area). The 'revised' targets were estimated to cost \$157/ha and still required significant land retirement (75% dairy land). Restricting land use activities to those traditionally funded and excluding land use change/retirement options increased costs from \$157 to \$292/ha. Overall these results imply that achieving large environmental gains involves major politically, socially and economically unacceptable impacts on grazing industries. The premise of 'win:win' outcomes, the basis of most publicly funded programs in Australia, is significantly challenged.

The results have been actively and adaptively used by the CMA to inform a realistic WQIP. Stakeholders recognised that the information base is imperfect and that refinement (finer scale catchment modelling and inclusion of heterogeneity in dairy and beef systems) could substantially reduce the estimated costs in achieving environmental outcomes. Bioeconomic modelling and active participation helped people understand the need for a more informed discussion about potential trade-offs between protecting environmental ecosystems and maintaining agricultural profitability. Policy choices involving targeted regulation to protect valuable ecosystems are likely to be needed, as is occurring elsewhere in the world.

Keywords: *Decision Support System (DSS), bioeconomic optimisation framework, water quality*

Implementing and adapting the WRON-RM Use Case categories for eReefs: aiming for Interoperable Systems' requirements analysis best practice

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Abstract: Multiple models, data services, sensor networks and other information tools are being embedded within complex and sometimes distributed architectures known as information platforms. These information platforms are increasingly being used to model multi-faceted environmental phenomena with one example being the eReefs project which will generate a near real-time view of lagoon water quality for the Great Barrier Reef. Not only may they involve many subsystems which must interoperate but they need to be able to evolve over time as new computational elements, sensor resources, models and datasets become available or cease to exist – for example a satellite's life ending.

To cater for both interoperability and evolution, system design must enable Use Cases – certain system behaviour – beyond those typically expected by end users such as data discovery and use. Use Cases for system maintenance, new subsystem addition, subsystem deprecation and overall information platform augmentation must be envisaged, articulated and catered for. For institutionally distributed information platforms such as eReefs, overall management and governance Use Cases are also of particular importance.

The Water Resources Observation Network's Reference Model (WRON-RM) provides the primary design framework for eReefs and it specifies six categories of Use Cases relevant to information platforms such as eReefs which were:

1. **End User** – processes of accessing information from an information platform
2. **Data Provision** – processes of contributing data to an information platform
3. **Functionality Provision** – processes of contributing data processing services
4. **Enablement and Governance** – processes of controlling various components
5. **Cross-business Domain Integration** – processes enabling integration with external systems
6. **System Maintenance** – processes associated with maintaining an information platform

The WRON-RM is both incomplete and untested with its preface stating: "It was recognised that Use Cases described in the document did not fully reflect the WRON and that the true Use Cases for the WRON were not well understood. As such, considerable work was going to be necessary to discover, describe and analyse these Use Cases in order to understand their impact on the requirements of the WRON."

This paper details how, by designing eReefs, some of that required work has taken place and how through building a concrete implementation of the WRON-RM, the extent to which the categorisation of Use Cases has helped the project. Specifically we relate: how Use Cases received from stakeholders, including most subsystem designers, fitted into the six Use Case categories; how the information platform's Scoping Study (Car *et. al.*, 2012) attempted to express Use Cases in all 6 categories; additions and modifications that have been made to these categories as functional requirements of eReefs have become clearer; specific Use Case examples from each generic category – the WRON-RM's six and additions and finally best practice methods regarding requirements gathering and stakeholder engagement for future information platforms attempting to provider similar functionality to eReefs.

Keywords: *Use Case analysis, interoperable systems, WRON, RM-ODP, eReefs*

An integrated model to examine the effects of Sustainable Diversion Limits: A case study in the Lower Campaspe catchment

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Abstract: Setting limits for consumptive water extraction from the Murray-Darling Basin, known as Sustainable Diversion Limits (SDLs), is a key feature of recent water reforms. The ecological and socio-economic impacts of SDLs have been assessed for the entire Murray-Darling Basin. However, there is still little understanding of how these limits will play out at the catchment scale and at more localised levels. To build this understanding, the SDLs (estimates and rules) need to be examined using a multidisciplinary framework that includes water management policies, climate change projections, the nature of surface water-groundwater systems, and water-dependent economic and ecological systems. This paper presents an ongoing collaborative project between the research team in the National Centre for Groundwater Research and Training (NCGRT), Victorian Department of Environment and Primary Industries, North Central Catchment Management Authority and Goulburn-Murray Water. It examines the effects of implementing the SDLs for the Lower Campaspe catchment in Victoria in terms of tradeoffs between the profitability of agricultural production and ecosystem response, especially groundwater dependent ecosystems. The model under development is also intended to be flexible enough to investigate adaptation options for landholders and water policy initiatives. In undertaking such an integrated assessment project, the research team brings together researchers from multiple disciplines, including hydrology, hydrogeology, ecology, resource economics, social science and systems science. The project has applied an integrated modelling approach which focuses on working closely with project stakeholders to identify modelling questions, share results and seek feedback. Our aim is to develop an integrated modelling framework that can be reapplied in other catchments to address stakeholders' questions and concerns with regard to the implementation of the SDLs at the local level. In this paper, we give a brief overview of the design of the integrated model under development, and its key components and interactions.

Keywords: *Integrated assessment, integrated modelling, tradeoffs, Sustainable Diversion Limits, Campaspe*

EXTENDED ABSTRACT ONLY

Integrated hydro-ecological-economic decision support framework for environmental water management

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Abstract: Providing water to the environment is an important strategy for maintaining and restoring ecosystem health in Australia and around the world. However, the extent of ecological and economic benefits of environmental watering is poorly understood. This information is important for assessing alternative ecological outcomes associated with different watering regimes and demonstrating 'value for money' in the supply and management of environmental water.

In this presentation, we will showcase an integrated hydro-ecological-economic approach for assessing the economic benefits of environmental watering in the Macquarie Marshes, Australia. The approach links a hydrological model (IQQM), an ecological model (IBIS) and a stated preference choice experiment (CE) study (Figure 1). The hydrological model estimates flow regimes for a particular volume of environmental water and its release strategy in a way that reflects the real policy challenges at the Marshes. The resulting spatially distributed ecological outcomes (e.g. suitable habitat condition for vegetation and waterbird breeding) are assessed using the ecological model. These ecological outcomes are then used to inform the design of the CE study. Finally, a primary household survey of the Australian population allows us to estimate the economic value of alternative uses of the environmental water at the Marshes.

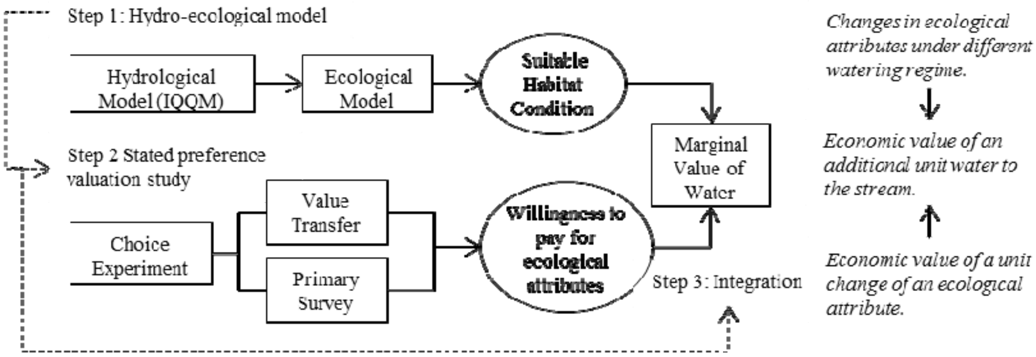

Figure 1: Conceptual framework of the integrated model.

This approach has several advantages. Firstly, the results help evaluate environmental watering options. For example, we can identify which watering strategies generate best ecological and economic outcomes per megaliter of environmental water and whether there is a unique solution. The CE survey generates an estimate of the marginal value of water used for the environment. Hence, it enables economic trade-off assessment water across its competing use, for example environmental use and irrigated agricultural use. If the marginal value of environmental use is greater than the marginal value of water in agriculture – the market price of water – then this means that water would be better traded off to environmental use. And thirdly, this approach provides an estimate of the 'optimal' use of water over environmental, economic and social goals, as required by the Australian *Water Act* (2007).

Keywords: *Integrated model, environmental water, habitat suitability, choice model*

An interactive modelling tool to support knowledge elicitation using extreme case models

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Abstract: Knowledge elicitation can be a crucial aspect of modelling. When few data are available, it enables predictions to be made on the basis of expert knowledge. It also provides the opportunity for stakeholders to express their understanding of a system to help assess a model and help ensure that their point of view is accounted for. In this paper, we describe an interactive modelling tool to help express and evaluate stakeholders' knowledge about water requirements of floodplain and wetland vegetation (Figure 1). It aims to maximise the breadth of views to which the user is exposed, and minimise mandatory user input. This helps prompt the user to reflect on their knowledge and empowers them to decide what they feel confident in claiming. This is achieved by automatically generating extreme case models (with different parameter values) for the user to evaluate even before they have given any input. Visualisations of these results prompt the user to provide information that constrains the models. These constraints take the form of key concepts of knowledge about suitability, namely the bounds (e.g. ideally, river red gums require 3-8 months of flooding) and relationship between any two points (e.g. 2 months flooding is better than 1 month flooding). This tool helps to capture uncertainty in elicited knowledge by identifying constraints rather than single models and expecting knowledge to be changeable and evolving. This contrasts with approaches that develop multiple consensus solutions, within which dissenting and novel understandings might be suppressed, and approaches that elicit uncertainty as measurable probabilities or possibilities which are themselves uncertain. Although we use a habitat suitability model as an example, this method is generic and can be used in many other applications eliciting relationships among variables.

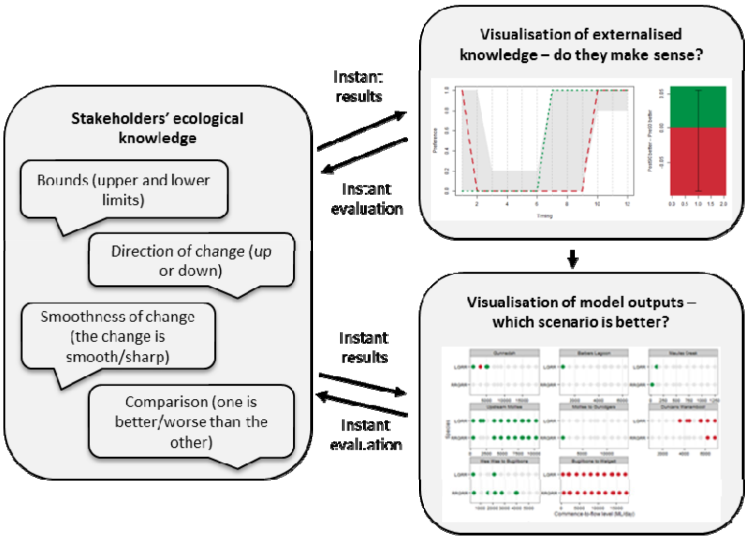

Figure 1: Conceptual framework of the interactive knowledge elicitation tool.

Keywords: *Knowledge elicitation, ecological model, habitat suitability, uncertainty*

On the Importance of Behavioral Operational Research: The Case of Understanding and Communicating about Dynamic Systems

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Abstract: This paper aims at describing behavioral operational research (BOR), a new research area defined as the study of behavioral aspects related to the use of operational research (OR) methods in modeling, problem solving and decision support. In operational research the goal is to help people in problem solving but somehow we seem to have omitted the individuals, the problem owners and the OR experts, who are engaged in the process, from the picture. There is a long tradition of discussing best practices in OR but it is surprising to note that behavioral research on the process itself and on the role of the analyst and problem owner has been almost completely ignored. Descriptions of case studies are not enough. We also need controlled comparative studies and experiments. We argue that by paying more attention to the analysis of the behavioral human factors related to the use of modeling in problem solving it is possible to integrate the insights of different approaches to improve the OR-practice of model-based problem solving.

Behavioral research in decision analysis and in our sister disciplines, game theory, economics and finance, is already very strong. It seems that interest in behavioral issues emerges when the basic theoretical core of the research field has matured enough. Economics is a good example. Behavioral economics has become an established topic acknowledged also by theoretical economists. Behavioral research in finance is very active as well. Embracing the behavioral perspective helps “generating theoretical insights, making better predictions, and suggesting better policy” (Camerer et al., 2004). If this is true for economics it surely applies to OR as well.

We identify areas of research where behavioral issues are important these include: Model building; Communication with and about models; Behavioral biases and cognitive aspects; Personal, social and group processes in OR facilitation; People in problem solving situations, learning, bounded rationality; Comparative analysis of procedures and best practices; Teaching of OR; Ethics and OR; Non-expert use of OR methods pitfalls and risks.

As an illustrative example we use well known system dynamics studies related to the understanding of accumulation. We show that one gets completely opposite results depending on the way the phenomenon is described and how the questions are phased and graphs used. The results suggest that OR processes are highly sensitive to various behavioral effects. As a result, we need to pay attention to the way we communicate about models as they are being increasingly used in addressing important problems like climate change. The paper related to this presentation has recently appeared in European Journal of Operational Research, Vol. 228, Issue 3, pp. 623-634.

Keywords: *Behavioral issues, modeling, OR practice, system dynamics*

Achieving Greater Real-world Impact of Research Outputs: It's not Rocket Science

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Abstract: Real-world uptake of research results is partially dependent on internal cultures of three types of research institutions. Their prevailing research cultures are characterised herein by their scientific mission, funding, targeted end-user, and time required to produce research results. The characterisations are generalisations that are nonetheless broadly applicable and useful for the issues raised in this paper. The table below summarises relevant aspects of the research cultures of the entities considered.

Research Entity	Mission	Funding	Targeted end-user	Time to Produce Results
Universities	Generate fundamental knowledge	Competitive grants	Other scientists with real-world users being "eventual" end-users	Longer time to produce outputs than other entities because research outputs are not time-sensitive
Public-Government Institutions	Serve the needs of government	Core internal funding supplemented by partnerships	Government and partners	Rapid for time-sensitive questions; relatively rapid for partner-based research.
Collaborative Research Entities (CREs)	Facilitate collaborative research among universities, government agencies, and private industry	Core funding from government supplemented by member contributions	CRE members who are real-world end-users themselves and connected to others	Variable depending on partners and nature of individual research activities

It is argued that the implicit assumption that better science – and the associated advancement of science-driven knowledge from a state of "complete ignorance" to "perfect knowledge" -- will necessarily lead to more adoption is incorrect. In fact, it is suggested that the greatest opportunity for adoption of research outputs occurs when one first moves from a state of "complete ignorance" because the marginal gains in real-world outcomes are much greater at this point than when knowledge advances from a state of being, for example, "90% complete." Moreover, it is suggested that as knowledge about a system/phenomenon advances, there is an "upper limit of practical utility" (ULPU) beyond which additional knowledge does not enhance opportunities for end-user adoption. This is because of both the potential economic costs of adopting more advanced science outputs, and the reality that in many situations once scientific knowledge has reached a certain level, considerations other than research results become at least as important in decision-making. Moreover, the marginal cost of advancing knowledge increases considerably above the ULPU making the cost-benefit ratio of additional research increasingly unattractive if the research goal is real-world adoption.

These factors are embodied in the title of this article which is a tongue-in-cheek reaction to the implicit belief that improved science – i.e., "rocket science" – is the key to better adoption. While better science outputs may be a necessary condition for a certain level of adoption, they are not a sufficient condition at all levels – i.e., above the ULPU. Hence the key to better adoption is not rocket science alone, but a combination of factors including some that are affected by different research cultures.

This article is based on the author's 25+ years of experience in a variety of research institutions.

Keywords: *Research adoption, institutional research cultures, data-based science, model embodiment*

Supporting agricultural policy – the role of scientists and analysts in managing political risk

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Abstract: This paper reflects on the role of scientists within research organisations and analysts within the Scottish Government in managing political risk for major policy changes. The particular change considered is the reform of direct payments to farmers through Pillar 1 of the Common Agricultural Policy, moving from payments based on historic entitlements to a multi-regional, area-based payment scheme. The move in Scotland to such payments is a major change in policy and one likely to result in significant redistribution in direct payments that underpin the financial viability of many businesses. The policy change thus involves considerable risk for stakeholders within the agri-food system but also politically for the Scottish Government for whom agriculture is an area of devolved responsibility. Considerable uncertainty surrounds the decision making process, partly as a result of EU processes requiring both EU Parliamentary and Member State agreement. Furthermore, the Scottish Government recognises and wishes to strike a balance between food production and associated economic activities conducted mainly in lowland areas and the ecosystem services delivered in the main by upland areas. Limited timescales for implementing the new policies also mean that research often needs to be undertaken before final decisions are made at EU and UK level.

The uncertainty in policy objectives and the spatial heterogeneity of Scotland's agricultural systems also mean that the policy options cannot easily be subjected to simple, single objective cost-benefit analysis. This policy uncertainty combined with a desire for the process of analysis to be transparent and inclusive meant that multiple scenarios, performance metrics and summaries were required by Scottish Government. The paper presents examples of the most important outputs for the spatial analysis framework and how these were used. Over the course of the research, it has become increasingly clear that political risk management in a complex and uncertain environment strongly shapes both the timing and use of research-based analysis. The paper shows how the research contributed to this risk management strategy by quantifying uncertainties, testing scenarios and communicating with stakeholders both formally and informally.

The paper concludes that the use of a spatial analysis framework was effective in highlighting the most significant redistribution effects – particularly those that occur within sectors or regions. These were useful to stakeholders in helping them articulate to government the likely adaptive responses from farming systems and to give an impression of the wider consequences for rural communities and the natural environment. From the experiences of working across the science-policy interface the authors conclude that simplistic structural models of science-policy interactions fail to provide diagnostic information needed to improve outcomes since they fail to represent the messy process of science-policy interaction. This process is dependent on the ability of individuals from either side of the science-policy interface to form mutually beneficial partnerships without compromising their independence. This network building is facilitated by the aim of the authors' research organisation to function as a boundary organisation, facilitating exchanges between science and policy and by the openness to close cooperation of individual analysts within Scottish Government analysis teams. There are significant differences in research cultures but sufficient common ground in terms of disciplinary skills, ontologies and epistemologies and common cause in tackling challenging policy risks. This capacity for cooperation is activated by Scottish Government funding models that support the long term development of strategically relevant research capacity, the building of networks and social capital bonds between analysts and scientists and additional flexible funding that can be deployed quickly by policy teams to address immediate questions. Within this environment, scientists can have a key role in bringing innovations into the analysis conducted in support of risk management, since their independence means they have greater freedom to work across Scottish Government departmental boundaries and within Scottish Government hierarchies. Success in this role, however, depends on institutional support for process wherein scientific credibility is translated into policy credibility incrementally through demonstration of salience, timeliness and adaptability.

Keywords: *science-policy, risk management, spatial analysis, research culture, common agricultural policy*

The shared IA toolbox

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Abstract: A key ambition in the development and use of models and software in impact assessment (IA) is to support the policy process with tools to evaluate the impacts of policy options on the three dimensions of sustainability: economic, environmental and social. To achieve this, IA tools need to be scientifically and technically sound, reliable, relevant to users, and widely applicable in a societally accepted participatory process. Various examples exist of complex and sophisticated models being applied in IA for policy making. However, in many cases, a gap persist between the currently realized and potential use of models in IA. Here, we will discuss causes and possible solutions for this.

We discuss how a lack of demonstrated robustness of model results, scarcity of documentation and usability of tools present barriers for uptake by potential users. This includes, but is not limited to, information about reliability, robustness, uncertainty as a lack of transparency, resulting in a 'black-box' perception of tools. It may result in evidence for IA not being deemed trustworthy. To overcome these problems, the LIAISE network of excellence developed a common reference framework and guiding structure (the Reference Model for Impact Assessment Tools, RM-IAT), which provides a starting point for developing a shared toolbox (Figure 1), bringing together information about tools, experts, best practices and related documents to support policy impact assessments.

Describing IA tools consistently following this framework gives users more information about the tools, scale of use, complexity, data requirements and application area, existing applications in IA, amongst many other parameters. The toolbox provides guidance to tool users for a better selection of tools for their specific purposes, which in turn may improve tool use in IAs. In addition, the toolbox is utilises taxonomies to classify not only tools, but also experts and best practices in a consistent fashion. The LIAISE Toolbox thus aims to serve as a central platform for the community of IA practitioners and researchers.

In order to make the contents of the toolbox available for other uses, we are investigating the options to expose the contents as linked open data on the web. Semantic Web technologies are being used to improve data discoverability, and to add meaning to the contents of the toolbox, so that it may be used for other goals in other applications. In addition, we try to enrich the contents of the toolbox by grabbing relevant information from other sources and display this additional information as additional content to what is stored in the toolbox itself. This will be accomplished by querying SPARQL endpoints from sources which have been identified as potentially useful.

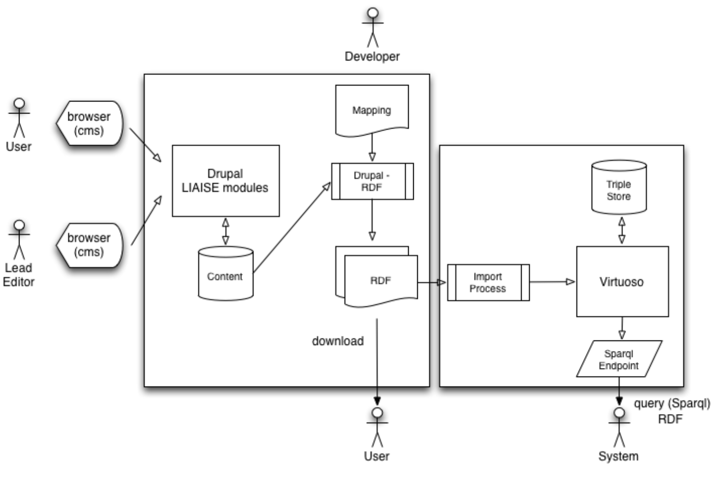

Figure 1. Schema of tool box architecture.

Keywords: *Impact assessment, Models, Toolbox, Science-policy interface*

Customer focused science and knowledge management for sustainability in New South Wales, Australia

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Abstract: The New South Wales (Australia) State Government's direction is set through its *'NSW 2021 : A plan to make NSW number one'* ten year strategic plan. Key to the government's reforms is the objective to increase the devolution of decision making to the community by providing open access to data, information and services via transparent processes. For the NSW Office of Environment and Heritage (OEH), this is achieved through 'The Open OEH' program. The vision is to make OEH data and services open, available, accessible and useful to the community anywhere and anytime. This requires customer focused delivery that may depend on cross agency collaborations to set and deliver priority outcomes.

Science within state government improves objective decision making at all levels and provides a lens through which often competing perspectives and demands from multiple customers may be better viewed and considered. The expectation is that science will 'bring to the table' and illuminate rigorous and transparent data and information on relevant issues and matters. OEH is seeking to better fulfil these expectations through its corporate emphasis on engaging customers. Understanding customer values is emerging as an important element in project management. A customer focus will progressively inform strategic priority setting for end to end project delivery of OEH science and knowledge management.

State government science does not duplicate that of other recognised science providers. Science within Federal Agencies and Universities is more exploratory in nature whereas state government science is directed research, often drawing information from imperfect/incomplete knowledge. This knowledge is enhanced through participatory end user engagement, which allows for understanding of the data limitations and assumptions. Critical to this process is the concept of scientist social capital; that is, the benefits that arise from the science practitioner's connections, reputation, status and relationships. Paramount to success is developing and maintaining trust with an often diverse customer base.

In the OEH the Science Division has undergone a major restructure to respond to the needs of NSW 2021. The new Ecosystem Management Science (EMS) branch consists of cross functional teams designed to deliver products and services to customers and colleagues undertaking policy and program design and delivery. The teams in the branch are headed by recognised scientific leaders who run programs using collective decision making. This seeks to optimise benefits from the science social capital of their connections, reputations and knowledge. It also enables them and their teams to work within a matrix management model to provide rapid and responsive science solutions while working towards long term strategic science program goals. There is a strong interdependency among all the EMS teams and this encourages interactions between individuals making possible a broad canvassing of ideas and knowledge.

An important feature of the EMS branch is that its six teams are orientated on outcomes rather than science disciplines. This acts to further facilitate improved access to science and knowledge across teams and greater sharing of project components. To enhance knowledge creation and flow to customers, a dedicated science Knowledge Service Team has been created to instill rigor in knowledge management and thus directly contribute to Open OEH. This team will be strongly supported by an Evaluation Team that uses modeling and decision support systems. These systems will provide transparent, repeatable forecasting and scenario analysis capabilities. Clear two-way communication, will increase customer engagement, understanding, evidence-based decision making and action. Ultimately this will lead to better informed and more transparent discussions about ecosystem management including options for trade-offs and multiple co-benefits from government decisions and community investment. This will boost prosperity and sustainability by empowering community and government decision makers to improve ecosystem services and better sustain landscape and community productivity and function.

Keywords: *Ecosystem management, knowledge management, science communication, NSW 2021*

An Environmental Management Plan in Vavouto harbor (New Caledonia) with a statistical treatment displayed on dynamic maps

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Abstract: This paper presents an environmental monitoring tool to control and share results in real time as part of an environmental management plan (EMP) associated with a major dredging operation in the northern part of the New Caledonian lagoon. The interoperable tool includes results collected by a network of sensors that monitor turbidity and other physicochemical parameters of both the water and sediment.

The tool was designed for the spatial and temporal monitoring of turbidity using interpolation maps at daily, weekly, monthly, and annual intervals.

The geostatistical method of kriging was chosen for interpolation of turbidity values from the network of sensors in Vavouto harbor. Several maps are produced that show turbidity values based on whether they are one-off on-site measurements or measurements recorded continuously by sensors with radio or manual transmission, along with the depth of the measurement.

The Open Geospatial Consortium (OGC) provides the framework for collecting, displaying, processing, and sharing results on dynamic maps to comply with international standards. These standards were used to produce a dynamic map, and water quality data from sensors installed in the lagoon near Vavouto were stored and shared using Observations and Measurements (O&M) and Sensor Observation Service (SOS) standards. This map, which provides results in real time, is accessible on the web.

The creation of a standardized tool for the acquisition and organization of data based on mathematical data processing methods enables an integrated approach to environmental management planning, and can be shared by all stakeholders.

Keywords: *Environmental management plan, water quality in the lagoon, interoperable tool, statistical treatment in real time, Open Geospatial Consortium standards*

Driving Data Management cultural change via automated provenance management systems

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Abstract: Large multi-disciplinary scientific projects that inform government policy and have a high public profile are often exposed to high levels of scrutiny. Such projects rely on a range of input datasets and modelling software packages and generate high volumes of output data, which are presented as summarised results in published reports. Defending the scientific integrity of project reporting requires that all project results have demonstrable integrity with clear evidence of the workflows and processes used to generate them, i.e. they must implement structured data management including provenance capture and storage.

Provenance data capture forms part of effective data management. The reporting of data provenance needs to occur in all workflows within a project and crucially needs support from project management, and adoption by project staff so that provenance chains are unbroken at every step, thus providing demonstrable integrity. Even when project funds and milestones are allocated to provenance tasks, such as ensuring staff store project datasets in managed locations and generate standardised dataset metadata records, data provenance capture has often been poor. This indicates that the barrier to the adoption of useful data provenance tasks is still significant. The development and application of automated systems, which capture and report provenance without additional user effort, are therefore of critical importance in helping to lower this barrier thus easing cultural change in data management.

Even if a project or organisation has motivation, has made the case, established a vision, and developed plans to implement provenance management, buy-in from all project staff is still required for success. This is because provenance chains containing information about data lifecycles need to be unbroken for all results, thus requiring involvement from all project staff. Some, perhaps the majority, of project processes cannot be automated, thus they will require significant manual effort in order to be included in provenance management.

This paper outlines previous best-practice regarding CSIRO's data management approach as demonstrated by the Murray Darling Basin Sustainable Yields project, and reflects on their shortcomings, such as the lack of adequate provenance capture, with improvements suggested. It then describes several automated provenance management tools that employ semantic web technologies and preserve the identity of provenance reports and datasets; which may be used to help with bottom-up practice adoption. The automated provenance management tools can provide well-defined, automated processes, which may help to lower the barriers preventing cultural change for data management at the project and organisational level.

It is hoped that the improved data management practices and the automated tools discussed here can inform current and new high-profile projects, such as the Bioregional Assessments program, to attain a higher quality of demonstrable data integrity through more robust provenance management.

Keywords: *Provenance, data management, cultural change, semantic web, metadata*

Making information models work harder

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Abstract: Information models are useful for representing concepts and relationships in a domain of discourse. These models are typically used to guide system design and implementation and are also used as documentation. Models are also used to assist with system integration enabling multiple stakeholders to agree on a common structure and semantics for sharing data. For example, information models developed in Unified Modelling Language (UML) developed according to ISO 19100 series standards may be used to develop Geography Markup Language schema which specify how geographic data may be encoded for exchange as XML.

In this paper we propose additional uses for UML information models, enabling them to be connected to additional information specifying the semantic content of data, and delivered using Linked Data approaches. We also describe the role of models in enabling transformation and integration of heterogeneous data to a common model.

We present two case studies (i) publishing a suite of related information models using the Water Data Transfer Format (WDTF) schema at the Australian Bureau of Meteorology and (ii) the use of information models for harvesting content in the Spatial Identifier Reference Framework (SIRF).

In the WDTF case study, model publication is underpinned by transformation of UML models to Web Ontology Language (OWL) ontologies based on a (draft) ISO standard. The models are published in a Feature Type Catalog (FTC) delivered through a RESTful interface. The FTC is implemented as a Linked Data application in which model elements are identified using URIs, with content negotiation to access HTML or OWL/RDF forms.

In the SIRF case study we describe how models and mapping between models are used to support transformation and integration of data, and are then published together with the integrated data using Linked Data approaches.

Keywords: *Information models, metadata, UML, OWL, Semantic Web, Linked Data*

A Governance Framework for Data Audit Trail creation in large multi-disciplinary projects

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Abstract: The creation of data audit trails, within large multi-disciplinary projects in the CSIRO Water for Healthy Country (WfHC) Research Flagship, have relied heavily on the development of appropriate data management tools for creating metadata and data audit trails, coupled with human and technological processes. However, having the tools and processes alone does not provide an effective data management system so we have established a Governance Framework which provides the holistic function of integrating the various teams, technologies, and tools in an organized and focused way.

The Governance Framework creates an environment where there are clear objectives, roles and responsibilities for handling data management activities, protocols, procedures, and processes for delivering the components of data, metadata, and audit trails, as well as providing a means of assigning accountability and developing incentives that ensure that audit trails are completed with a high degree of confidence. While the Governance Framework forms a holistic function it does require the application of an efficient tool for cataloguing data and constructing data audit trails with provenance information.

A metadata tool was originally developed in 2007 by CSIRO Land and Water through the WfHC Flagship. The main need for the metadata tool was for capturing a data audit trail for a basin-wide multi-disciplinary project known as the Murray Darling Basin Sustainable Yields (MDBSY) project. The tool was later modified to accommodate additional Sustainable Yields (SY) projects between 2008 and 2010 and proved a valuable asset as a data auditing platform for such high-profile projects. The modified tool still had some limitations and did not fully conform to a metadata standard. In 2011 the tool, known as the Regional Water Data Management System (RWDMS), was rebuilt to meet the ANZLIC metadata standard and with improvements in functionality.

Based on a similar architecture to the original tool, the RWDMS has various new features such as metadata statistics, the ability to add new projects via the web interface, and import and export functionality. In addition, it now also provides the ability to generate audit trail lineage diagrams to depict the genesis of data throughout a project via parent-child relationships that are defined in a lineage field during metadata entry. The RWDMS is also able to export metadata in ANZLIC XML format, which can then be imported into the CSIRO Enterprise, Data Access Portal (DAP) for wider access. The tool includes a web-based user interface, a relational database for storing the metadata, and a metadata 'robot' which scans the data storage file system to detect new datasets placed there and then create blank records in the database, ready for manual metadata attribute population via the web interface.

The RWDMS has been effectively applied to the creation of data audit trails. It relies on an underlying project data archive file structure with clearly defined directories and a naming convention which flags datasets so they can be detected by the metadata 'robot' and then catalogued by the user. The parent-child linkages are then defined for each dataset to create an audit trail which can be visualized within the RWDMS interface.

The Governance Framework has created a vital operational environment for managing project data in the CSIRO, WfHC Flagship while the RWDMS provides a highly functional toolset for cataloguing data, for monitoring archive construction and data custodian input statistics, for reporting of project metadata statistics, for viewing audit trail diagrams, which depict project data genesis through parent-child linkages, and a process for publishing data products into the CSIRO Enterprise DAP, post-project, for wider data discovery and reuse. While there are still limitations in the capture of good quality provenance information, future developments in the capture of project workflows and automation of provenance capture will further enhance this system and provide further support to the development of a coherent data management culture.

Keywords: *Data cataloguing, data audit trails, data discovery, metadata*

Harmonising Web Feeds for Emergency Management

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Abstract:

The Emergency Response Intelligence Capability (ERIC) project is a CSIRO collaboration with the Emergency Management team from the Australian Government Department of Human Services. CSIRO have developed a tool that collects emergency event information from 'live' web feeds published by emergency service agencies and records it in a database. A web feed is a web accessible resource that is updated frequently as new information becomes available from the content provider. This information is made available along with statistical regions and demographics data from the Australian Bureau of Statistics and departmental regional profile data. This allows information for a specific region under investigation to be readily available in the context of the changing status of emergency events. It also provides an archive of the 'live' web feed contents for historical review and analysis, and is a backup when the source is unavailable due to web site outages.

The Emergency Management team monitor emergency events across the country and are responsible for intelligence gathering and situation reporting for the department during emergency events. This information is used to help coordinate the department's response to emergencies, with a focus on delivery of services on behalf of Government for the Australian community. These activities are manual and time consuming, requiring the attention of several staff to obtain and assemble the required information into the appropriate structure and format to produce a situation report. Some of these tasks can be automated allowing emergency coordinators to better utilise their time in the analysis of information rather than finding, collating and formatting it.

In summary, the ERIC tool automatically gathers information from a range of dynamic data sources (the web feeds), stores it in a database, presents the information online using a map, includes a large collection of static data and provides easy access to the information via an interactive map and 'popups'. The tool also provides new functions: the user is notified when new relevant information is available; they can review details of events that have occurred in the past; the user can search for specific events by category, location and source; customised situation reports can be generated for different types of emergency events at specific locations; and a repository of situation reports is maintained. A public version of the tool is available at `http://eric.csiro.au` which has fewer features available, the departmental data is removed and no situation reporting, but it is useful for other agencies to understand the core ERIC features of data integration.

The ERIC tool can be considered a centralised data warehouse replicating the data holdings of the web feed custodians. The contributing sources of emergency event information are heterogeneous in many ways. For example the web feeds publish information using various formats (mostly using structured text), use different conventions for identifying events (using combinations of name, event type, location and severity), publish data updates with different frequency, describe similar events in different and sometimes inconsistent ways, and use the same descriptive labels with different meanings. Maintaining a consistent amalgamated copy of the contributing web feeds is difficult in practice due to these differences in the source systems.

An overview of the various web feeds is presented outlining their structure and content. A detailed description of information recorded from seven web feeds managed by state and territory based fire agencies is analysed noting their differences and similarities. For the period starting early October through to the end of March 2013, there were almost 44,000 individual web feed fire reports recorded describing over 15,500 different fire events, of which 162 were categorised as a *Fire Emergency*. This information is a valuable source of intelligence for situational awareness to emergency managers.

This case study highlights the differing data management practices currently used by the state emergency services and the steps undertaken in ERIC to develop a nationally consistent model of this information.

Keywords: *Crisis coordination, disaster management, situation awareness, web feeds, social media*

Data and information management for integrated research – requirements, experiences and solutions

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Abstract: Environmental management and related interdisciplinary research address a wide range of data and information management demands. The collaborative use of respective data requires providing descriptive meta-information as well as functionality for their storage and access. Further, a detailed and fine-grained permission management is important to preserve intellectual property rights and thus to build-up trust into such systems. A variety of readily available software tools, and standards for data exchange and processing, supports the assembly and deployment of appropriate data management and data sharing platforms that address these requirements and assist researchers to find, access, store, describe, process and disseminate data and results. An example of these systems is the modular-structured, web-based River Basin Information System (RBIS) developed in the Department of Geoinformatics, Hydrology and Modelling at the University of Jena. RBIS focuses on the management of metadata and data (e.g. time series data, geospatial data) and the provisioning of standard compliant data exchange interfaces and services (e.g. WaterML and CSW). RBIS currently has been applied in more than 20 environmental research projects as a data management and sharing platform to support single researchers, bilateral research activities and multi-disciplinary research projects during project runtime and beyond. Environmental data (e.g. Time series and geospatial data) are gathered, preprocessed and made available via interfaces for external applications (e.g. environmental models). Moreover, interim and final results can be shared with project partners as well as local stakeholders. The development of the core system and modules has followed technical, economical and functional requirements raised in integrated environmental research projects during recent years during which RBIS was applied and enhanced. The most important components and their implementation can be summarized as follows:

- **Open source:** To support reuse and extensibility of software, RBIS is based on open source software (e.g. PostgreSQL, PHP, JQuery, UNM MapServer, OpenLayers, pycsw, …).
- **Online / offline access**: RBIS is web-based, but due to the fact that many regions of the world have a unreliable internet connectivity and for an easy distribution, RBIS may also be operated in a virtual server environment to allow for offline accessibility.
- **Flexible and extensible**: To build a system which is flexible, scalable and easy to extend according to actual requirements, RBIS is structured in a modular way using a data description layer to encode the visualization, manipulation and linking of datasets as well as the internal representation of the data in the database.
- **Permission management**: In order to provide a platform for data sharing, a fine-grained user and permission management process was implemented, which includes the ability to apply restrictions to datasets, RBIS modules, and related actions.
- **Interfaces and services**: To expose data on the internet and to exchange data with other applications (e.g. modeling tools), standard compliant interfaces and services are provided (e.g. CSW and WaterML).
- **User acceptance and trust**: In order to raise acceptance, motivate, and build trust, it is not enough to provide a technical solution, but rather to develop training courses for data providers and users, as well as a multilingual web interface, online tutorials and comprehensive support. Additional group communication functions, such as a simple internal calendar, as well as an automatic notification about new or changed events or stored datasets, can also contribute to assist end users.

RBIS is seen as a technical contribution to integrated research projects for bringing different data types and disciplines together, to support different steps in scientific workflows and to assist in the sharing and dissemination of research results.

Keywords: *Environmental information system, research project data management, time series data, geospatial data, data sharing*

Net Benefit Assessment of Illustrative Climate Adaptation Policy for Built Assets

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Abstract: We report on the modeling and initial results from the first national-scale integrated assessment of costs and benefits of different climate adaptation policy approaches affecting built assets at statistical local area resolution. In this study we simulated damage incurred from coastal inundation hazard under three climate outlooks. At all stages, from inception to review of results, our key stakeholders were involved notably as sources of policy innovation, and as guides to the logic of policy action; enabling codification of climate adaptation responses according to stylized policy stances. These stances represented different levels of caution and different approaches to implementing three general adaptation actions: avoidance, accommodation and protection. The performance of each stance was defined by the benefit of avoided damage costs compared to the cost of climate adaptation action measured in net present value terms. Absolute measures of policy merit have been averted because of the epistemic uncertainty in the modeling of such a multi-dimensional space over a national scale, combined with considerable variance in climate inputs. Therefore, performance of policy stances, under each of the climate outlooks, is presented relative to a non-adaptive case that continues the use of current construction standards and approaches to climate adaptation. This comparison of relative merit provides new insight to inform policy-making and contributes to the development of adaptation science.

Keywords: *Climate adaptation, policy simulation, coastal inundation*

Supporting Regional Natural Resource Management (NRM) organisations to update their NRM plans for adaptation to climate change

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Abstract: Our paper presents an innovative co-research approach to addressing the challenges faced by Australian NRM organisations in managing the impacts of climate change on natural resources. The project involves four regional NRM organisations and researchers from two major research institutions. The four NRM organisations in the 'Wet Tropics Cluster' (WTC) are: (i) Reef Catchments NRM, (ii) Terrain NRM, (iii) Cape York NRM, and (iv) Torres Strait Regional Authority. They cover the major part of the far north-eastern coastal region of Queensland, Australia. This region is recognised globally for its outstanding natural values and NRM organisations are responsible for meeting international obligations to manage and maintain the high biodiversity values as well as balancing a wide range of social, economic, cultural and environmental needs. In the face of a changing climate, NRM organisations are required to also incorporate planning strategies that are aimed at mitigating and adapting to the impacts of climate change. This project is aimed at supporting NRM organisations in their planning, first by establishing a 'Brokering Hub' for the WTC, which brings together researchers and NRM organisations to guide the work of the WTC and facilitate the development and communication of new knowledge and tools. The research component of the Brokering Hub is divided into three 'Science Nodes', one of which is the 'Participatory Scenarios and Knowledge Integration Node. (Figure 1). Our initial work in this Node has focused on the identification of focal issues and key drivers of change in the four NRM regions through a participatory process with members of the Brokering Hub. The results from this process have highlighted similarities and key differences between regions, indicating the specific scientific information needs required by each NRM organisation to develop potential climate adaption responses. In order to address the issues and information needs of NRM organisations, new knowledge and tools will be generated by the Science Nodes in collaboration with the NRM organisations. Our innovative co-research approach equips the regions well for this task.

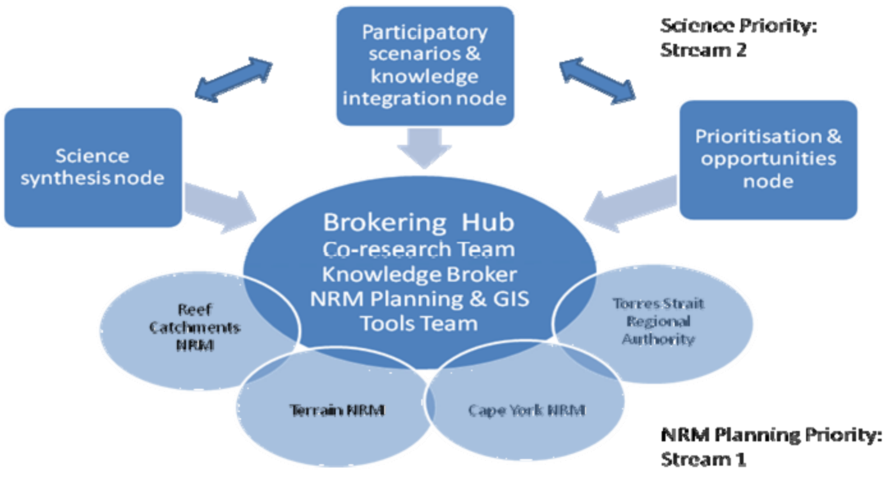

Figure 1. Co-research approach that promotes long-term system well-being and collective learning.

Keywords: *Co-research, collective learning, knowledge broker, transdisciplinary research*

Experiences of user engagement and perceptions of user needs: providers of future climate information on the usefulness of the information they provide users for decision-making

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Abstract: Adaptation is needed across many primary industry sectors to effectively manage the impacts of climate change. While future climate information exists to support adaptation decision-making, who ensures that the types and scales of information produced adequately support the needs of decision makers? This paper presents analysis of in-depth, semi-structured interviews with scientists who provide future climate information to groups of on-ground decision-makers in various sectors. Some of the scientists directly produce climate information using climate models, while others supply and/or transform the data into other forms for their users. The purpose was to explore the scientists' perceptions regarding the usefulness (to users) of the future climate information they and others are providing to users in various sectors, with a focus on the primary industries.

The scientists worked with different user groups, and considered different types of climate information to be useful to the users' needs. Most of the interview participants expressed a good understanding of the types and resolution of climate information that their users found useful, and acknowledged that climate information was not the be-all and end-all of decision-making. Participants also indicated a common understanding that bridging the gap between supply and demand of useful information means understanding and working within users' existing abilities, processes and decision spheres, and that open dialogue from the outset of projects would help to achieve that.

Key themes discussed included observations about whether co-production is a dominant mode of interaction between providers and users of information; whether users are necessarily in the best position to decide on what information they actually need; the types of future climate information provided to users; whether users require higher resolution climate information, such as that from downscaled models, to assist their adaptation decision making; whether users in general have a good or poor understanding of the uncertainty associated with the desired information; who dictates 'usefulness' of scientific research; and the focus within the community of climate information providers on providing credible and legitimate information for users.

This study provides an example of co-production of future climate information happening in specific on-ground situations. The general opinion expressed by most interviewees was that co-production is occurring more often than previously, but to different extents in different communities or sectors; and that co-producing information is only appropriate for certain desired impacts. The majority of interview participants were well aware of their users' needs. This indicates that a progression in the mode of interaction may be occurring in this area. While providers are unable to provide some kinds of information that their users request – due, for example, to the lack of time and funding available – they are able but cautious to provide future climate information in the format considered most useful for long-term adaptation decision-making by certain users.

The ideas of co-production of information and a decision-centric approach to information provision are not new – however, this research seeks to explore whether the ideas prevalent in the literature are matched by the current agenda and actions of these providers of climate information.

Keywords: *Climate change adaptation, Decision-makers, Usefulness of information types, Co-production, Resolution*

Informing the future of Australian mining through climate change scenarios

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Abstract: Mining value chains are vulnerable to a changing climate mainly due to the likelihood of increases in the incidence of extreme weather events. As such events will potentially become more frequent and more intense, the associated impacts such as infrastructure damage, production delays and downtime may damage mine profitability, staff safety, company reputation, regional 'liveability' and government revenues. Mining adaptation strategies to better deal with such impacts can be developed but the options available cannot simply be applied 'across the board' at all mines and in all situations.

Various types of mining in Australia occur across 11 main geographic areas, each with its own processes and needs, its own climate signature and its own extreme-event profile. To provide some context for the likely changes in future climate, CSIRO has developed mining region-specific scenarios in association with the OzClim Climate Change Scenario Generator. OzClim generates climate change scenarios using pattern scaling where the change at a particular grid point is normalised by the mean global warming produced by the model for a doubled CO_2 concentration in the atmosphere. The patterns of change are produced for each of the 23 global climate models and for the purposes of the Australian mining regions, we have expressed changes consistent with an historical baseline in order to make the projection information as contextually relevant as possible.

To bridge the gap between scenarios and users, CSIRO facilitated workshop events in mining regions. Representatives of a cross-section of the mining chain (including energy, mining, transport, research, water and community stakeholders) were invited to attend, some of whom were first interviewed by facilitators to gain an insight into their operations, understandings, and needs with regard to the workshop. The attendees were presented with future regional climate scenarios, additional information from other studies and climate location analogues helping to further 'set the scene' for the future and helping to facilitate discussion around potential impacts and adaptation needs. Discussions at the workshops provided the means for the scenarios to be placed in their local context, whilst hearing how others in the chain may be directly and indirectly impacted and how they may adapt.

Mines and their related infrastructure are frequently long-term investments for all concerned. Therefore, future climate scenarios are valuable for mining value chains and the decision-makers to envisage and plan the future, including adaptation at established sites, alternative processes at new sites and contingency plans that accommodate new levels of variability. Utilising workshops to link future climate scenarios to the value chain and its operational components assisted the end-users to visualise, conceptualise and engage with adaptation decision-making scenarios. The event also brought together participants from different parts of the mining chain who were able to share knowledge and discuss needs that may in the future aid adaptation and avoid maladaptation.

Keywords: *Mining, climate change, scenarios, workshop*

Worth a thousand words: Connecting tourism operators with climate change through visualisation techniques

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Abstract: The old saying "a picture paints a thousand words" has never been more appropriate when discussing the issue of communicating climate scenarios. Our research demonstrates the benefits of using imagery creatively to effectively communicate large amounts of scientific information in a powerful, easy to understand format for tourism operators in Queensland's Sunshine Coast. Globally, tourism has been identified as an industry in the 'climate danger zone', where risks are significant but many operators remain unprepared. Tourism is Australia's second-largest export earner, yet the industry is comprised primarily of small businesses managed by individuals with limited business experience and training. The combination of a lack of awareness, capability and preparation for potential climate risks coupled with poor engagement with adaptation options, places one of Australia's most valuable assets in a vulnerable situation.

Using a multi-disciplinary approach, the research combined projections from climate scientists with tourism operator perceptions of climate change and adaptation, gathered through an engagement process consisting of interviews and workshops conducted over eight months. The process involved five stages of engagement and consultation with industry prior to the release of a final product. The result is a visual and interactive PDF used to communicate the scenarios across the industry in the designated region, wherein users can self-navigate at their own pace. The tool itself has initially been well received when it was road tested with tourism operators with only minor suggestions for improvements.

As a result of the positive response it appears there are multiple additional applications either used across different industry sectors or across various climatic regions. For example, it has been suggested that such a process could be used to develop a tool for different regions of Australia that various industry and small business operators working in that area could use to help inform them about likely climate impacts and therefore plan accordingly. In addition, the process of developing the tool has encouraged climate scientists to become more aware of end-user needs and how to adapt their science to improve its relevance across society. The tool itself provides a mechanism that is a low cost way of encouraging ongoing climate action.

Keywords: *climate change scenarios, communication, end-users, visualisation*

Assessing urban water security and climate change adaptation in Makassar, Indonesia

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Abstract: Understanding the potential implications of global and regional climate change is important for decision-makers and planners to make better decisions regarding infrastructure needs and future planning. This is particularly important in cities in developing regions, which often have a history of under-investment in infrastructure and services and experience constraints in finance, resource access, limited data and capacity, whilst experiencing rapid population and economic growth. Makassar city, the capital of South Sulawesi, Indonesia, is a typical example. With a population of 1.3 million people, increasing access to clean water supply to a millennium development goal level is a key government objective. However, access to water depends on multiple factors: the city's surface water supplies which are subject to strong seasonal effects, the availability and condition of the infrastructure for water treatment and distribution, water use patterns and the resources and capacity of the city to invest and maintain their system.

To aid in the assessment of water security and to build the capacity in the region, CSIRO and Hasanuddin University in conjunction with local government agencies developed a framework for water security assessment (Figure 1). The framework included climate change projections, evaluated its potential impacts on surface water hydrology and urban water security for Makassar city and then focused on the development of adaptation options. Integral to the development of the framework was the participation of stakeholders (government agencies, researchers, NGOs and academics) at all stages of the process. By integrating top-down and bottom up knowledge (scientific modelling outputs and local knowledge) the project was able to identify vulnerabilities and assess the effectiveness of planned infrastructure to climate change and urban development and to identify a range of adaptation options which can assist in increasing the future security of water supply.

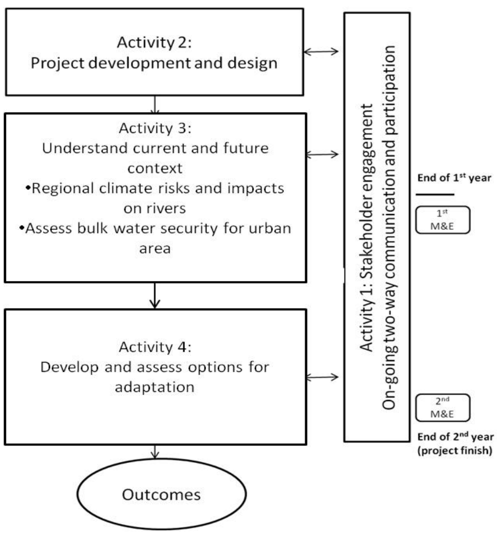

Figure 1. Framework for water security assessment and capacity building (Adapted from Kirono *et al* 2013)

Keywords: *Sustainable urban development, climate change adaptation, hydrological modelling*

Increased Urban Heat Island Effect due to Building Height Increase

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Abstract: An increase in urban population with only limited space to extend urban development forces city planners to think upwards. Adelaide, South Australia is one example where height restrictions in the central business district (CBD) were recently lifted to allow for a projected increase in urban population. The city provides a unique study area for the analysis of the urban induced heat variation. The main CBD is small compared to most cities around the world. The CBD covers only four square kilometres and is surrounded by a 500 metre wide parkland belt with sparse vegetation.

Adelaide's temperature distribution has been monitored by twenty temperature sensors in the CBD and parklands since winter 2010. The observations exhibit a maximum temperature difference between the CBD and parklands of 6°C; with an average of 1.5°C. The maximum temperature difference occurs around sunrise and the winter UHI effect is more marked than in summer.

Using a sky view factor which includes information of the wind (effective sky view factor, ESVF), the change in temperature depending on the height variation is in excess of 1°C. This, in connection with a projected temperature increase due to climate change, has major implications to energy use and carbon emissions in the future.

A micro-scale urban model (ENVI-Met) has been employed to study the influence of building height on the surrounding UHI effect. The modeling of a simple street canyon displays the relation between building height and street width and hence confirms the results exhibited by the effective sky view factor. However, the simple street canyon simulations with ENVI-Met show that when building height reaches street width, the increase in temperature at street level stops and even reverses for higher building heights. The model may lack significant processes (e.g. heat transfer between inside and outside of the buildings). Observations show that shading of surface area and heat storage processes in the walls are important contributions to the atmospheric temperature.

ENVI-Met Version 3.1 does not include heat storage in building walls. Heat transport between inside and outside of buildings is treated as an in situ process. This missing process is a possible explanation in the reversal of the diurnal temperature change in the simple cases when building height reaches street width. It is also likely the reason that a lower average temperature is modeled in a complex city setting when double building height is simulated and compared to the control case.

Further investigation of the atmospheric processes and their effect on the near surface temperature is needed. Modeling here is still in progress and further simulations, especially for the complex Adelaide CBD, cases are necessary.

Keywords: *Urban heat island, energy balance, micro-scale modeling, surface characteristics*

Marrying Exploratory Modelling to Strategic Planning: Towards Participatory Model Use

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Abstract: Long-term strategic planning in the context of urban systems involves uncertainties beyond mere error margins on assumptions and predictions. Exploratory modelling, as opposed to the well-established predictive/deterministic modelling, has emerged to cope with, rather than reduce, uncertainty in this realm. However, the scholarly commentary is largely silent, despite its advocacy, on how this type of modelling is integrated into a participatory strategic planning context. In particular, these models are often regarded as tools to support planning; but the process methodologies for model use in a participatory setting are not well- developed. To form the underpinnings of such a methodology, this paper puts forward a theoretical rationale that justifies how exploratory modelling techniques may contribute to fulfilment of participatory strategic planning objectives. To do so, the main objectives of strategic planning in the public sector are extracted from the literature and outlined. Then an overview of the social scenario modelling literature, mainly involving exploratory modelling, is presented and the main features of this type of modelling are derived. It is then discussed that a critical element that hinders the fulfilment of strategic planning objectives, as highlighted in literature, is the cognitive limitations of planners and decision makers to process and to use information and their over-reliance on limited experience to anticipate the future. The pitfalls resulting from such human limitations include frame-blindness, cognitive biases and false attributions of causality. According to the theoretical rationale developed in this paper, exploratory modelling brings a portfolio of possible futures and strategy outcomes, which are normally beyond direct experience, to a perceivable sphere for planners and decision makers. Therefore, a virtual experience of possible future realities will be created. This may challenge the mental frames of the planners, reduce cognitive biases in scenario planning and facilitate following long and dynamic sequences of causes and effects. The result might be pre-maturation of the participants' perception about future issues and strategy outcomes. Consequently, fulfilment of strategic planning objectives in practice would be more likely. This rationale underpins the research agenda for development of a currently absent process methodology that incorporates exploratory modelling approaches within a participatory strategic planning context. This methodology shall aim to strengthen the perceptions' maturation process and circumvent the aforementioned pitfalls. The ingredients of such a process methodology may include but are not necessarily limited to: using scenarios for visioning and arriving at shared perspectives, facilitating strategy experiments and performing robustness analyses across various strategies.

Keywords: *Exploratory modelling, strategic planning, participatory, public sector, uncertainty*

Towards building an integrated urban water system model to inform the identification of optimal water source mixes for Adelaide

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Abstract: The South Australian Water for Good Strategy outlines the actions that are required to ensure South Australia's water supplies are secure, safe, reliable and able to sustain continued growth. It supports diversification of supplies to reduce the reliance on rain-dependant sources. A study has been initiated by the Goyder Institute for Water Research in this regard, in particular to inform the identification of optimal mixes of water sources for metropolitan Adelaide. As part of this study an integrated system simulation model of metropolitan Adelaide's water system is being developed. This is to quantify supply implications and stormwater and wastewater discharges at defined points in the urban water system, when utilising different mixes of water sources, under both historical and future climatic conditions. This information is used to evaluate an objective function that aims at minimising life cycle cost of infrastructure, energy consumption and the potential impact on Adelaide's coastal waters, and maximising supply security, as part of a multi-objective optimisation based decision-support framework. The aim of the decision-support framework is to generate knowledge that can support the identification of the most cost-effective mix of fit-for-purpose water sources available to meet the needs of the community in metropolitan Adelaide, in an environmentally and financially sustainable manner. The sources to be considered are River Murray, surface water from Mount Lofty Ranges catchments, desalinated sea water, recycled wastewater, stormwater including roof water, ground water and the potable water savings through various demand management options. The objective of this paper is to describe the process followed to develop the simulation component of the combined simulation-optimisation approach.

The modelling platform used to develop the simulation model is Source Integrated Modelling System (IMS), which is emerging as Australia's national hydrologic modelling platform for river basins. Hence it has not been applied widely yet, particularly for urban water systems. The study reported in this paper one of the first application of eWater Source to urban water systems. The application process has been an exploratory process where modelling methods have to be developed for the each water source considered in this study using the available functionalities. Also, there are modelling methods currently in place in most cities to inform planning and operation of each city's water supply system. In general, when a new modelling method is introduced, quantitative evidence is required to demonstrate the performance of the new methodology is comparable to that of the existing methodology. Thus the process to develop the simulation component of the simulation-optimisation approach was staged and comprised the development of firstly a Test Case, secondly a Base Case before developing the Scenario Cases. In this paper, we describe the Test Case and the Base Case. Development of Scenario Cases is in progress. The purpose of the Test Case is to examine the ability of the eWater Source to represent key features of metro Adelaide's water supply system, to an adequate level. The 'adequacy' was defined as the ability of eWater Source to generate outputs (e.g. pumping volumes and storage volumes) of a similar order of magnitude from an existing water supply planning and operation model that is currently used by the South Australian Water Corporation. The Base Case model represents the 'business as usual' scenario for supplying water from the three main drinking water supply sources for Adelaide, i.e. River Murray, Mount Lofty Ranges catchments and Adelaide Desalination Plant. The simulation is performed over 50 years, on a monthly basis. The optimisation time horizon is 25 years, from 2013. The simulation model is provided with functionalities using the Expression Editor capability in the eWater Source to evaluate the objective function, consisting of net present value of life cycle cost of infrastructure, energy consumption and the volumetric reliability of supply. Development of Scenario Cases is in progress, which will include adding the other sources mentioned above. The Scenario Cases will also provide information to minimise potential impact of wastewater and stormwater discharges to Adelaide's coastal waters. The results of the Test Case showed that eWater Source can adequately represent the existing water sources in Adelaide's water supply. The results of the Base Case showed that eWater Source can produce the expected behaviour of the supply system. The project is in progress.

***Keywords**:* *Adelaide, eWater Source, Optimal Water Mix, Integrated system modelling, Urban water*

Integrated assessment of water management strategies: framework and case study

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Abstract: Over half of the world's population lives in sizable cities, and in many of these cities, urban water managers struggle to provide safe water supplies while maintaining the health of the environment. Can Tho, at the heart of the Mekong Delta, is trying to plan for sustainable urban development when faced with by rapid population growth and industrialization, changes to the hydrology of the Mekong, and challenges related to climate change.

A previous study used an iterative process of stakeholder engagement workshops, data collection and householder survey to identify and evaluate water management strategies that would support sustainable urban development in Can Tho. These activities highlighted the water-related needs of the city, using the Water Needs Index, and developed possible strategies to address the arising issues. These strategies were evaluated using Bayesian Network Analysis to test for viability in the local context, and holistic system effectiveness. This is an integrated assessment methodology applicable not only for Can Tho, but suitable to other cities or regions. Stakeholder engagement is an important aspect of this process that promoted local ownership, and common understandings of outcomes and research results. The integrated methodology gained considerable traction in the local context, with funding agencies and local government either adopting, or wanting to adopt the recommendations arising from the study. The paper outlines the framework for assessment and integration of research activities to inform planning and implementation of urban or regional water management strategies through the experiences in Can Tho.

The applied framework has five steps designed to move from an exploration of the local context, towards the identification and preparation for management strategy implementation:

1. Develop an understanding of the local context, and generate baseline information as a foundation for subsequent steps.
2. Identify the city's needs, in terms of water management, or water-related issues, as defined by of the six dimensions in the Water Needs Index approach.
3. Identify and short-list possible strategies to be further developed and planned.
4. Assess the short-listed strategies for their likelihood of achieving desired goals, and their performance, against the Water Needs Index assessment, conducted using a participatory modeling approach involving Bayesian Networks.
5. Demonstrate and pilot the selected strategies, and plan for subsequent strategic implementation.

As part of this process, we identify the responsibilities and tasks required to ensure the success of short-listed strategies. The process also identifies important institutional factors and barriers to identified strategies.

The approach primarily builds on the lead author's studies in the Pacific Islands, and on the research team's experiences in applying the Integrated Urban Water Management approach. This is the first large scale application of the framework, and it has been shown to be a surprisingly effective way of engaging local stakeholders around the problem of water management who then have shown significant motivation to action and adopt other project outcomes. It is the authors' belief that the approach can be successfully applied in different contexts and most likely also to other sectors; although this may require some amount of process appraisals.

Keywords: *Integrated assessment; Integrated Urban Water Management; Bayesian Networks; Water Needs Index*

Integrated assessment of future water security: the case of Makassar, Indonesia

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Abstract: In many urban areas, population growth and changes associated with climate change are likely to increase pressure on water resources. One such location is Makassar City, located in South Sulawesi, Indonesia, which is experiencing rapid growth, urban sprawling and an increase in freshwater demand but faces a possible reduction in water availability due to climate change.

A study, as part of the CSIRO-AusAID Research for Development Alliance, combined climate change, hydrological and resource allocation modelling to examine water security and the resilience of planned infrastructure to climate change impacts. Rainfall and potential evapotranspiration from 5 different Global Circulation Models (GCMs) were statistically downscaled using the CSIRO Conformal Cubic Atmospheric Model, CCAM (McGregor and Dix, 2008). The downscaled rainfall and potential evapotranspiration were used in a hydrological model (SIMHYD) to estimate changes in streamflow for the two rivers which supply Makassar City.

As shown in Figure 1 (right), although the CCAM projections show a reasonable variation for the projections of streamflow for both the Maros and Jennebarang catchments, all CCAM based projections of future streamflow agree on a reduction compared to historical records. The future predictions of streamflow indicate a reduction of mean annual streamflow in the order of 0-25 %, with reductions in the mean wet season flow of the same order when compared to the period 1980-1999. The reductions in streamflow for the dry season are projected to be between 5-35%.

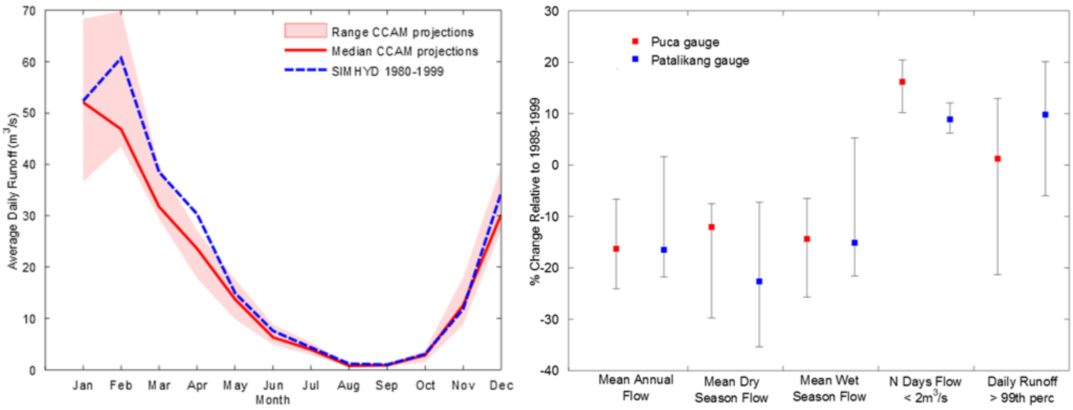

Figure 1. Predicted average daily runoff for the Puca gauge for the period 2020-2040 (left) and percent changes for mean annual, dry and wet season, number of days with flow below 2m^3/s and 99th flow percentile for the periods 2020-2040 (right) at the Puca (red symbols) and Patalikang gauges (blue symbols).

The streamflow projections were combined with population projections, infrastructure development plans and water demand estimates to assess future scenarios of water supply capacity for the city, using the REsource ALlocation Model (REALM) software. Results indicate that under the assumed scenarios sufficient inflow for urban water allocation alone will be available during the wet season. However, during the dry season Makassar is likely to face supply problems not only due to reduction in streamflows, but mainly due to infrastructure constraints, population growth and competing water uses. The analysis suggests that the future water security in Makassar will depend on its ability to plan infrastructure and manage water demand despite of climate change. The information generated in this study has allowed key stakeholders to gain greater insight into the future water resource pressures and to re-assess adaptation options.

Keywords: *Hydrological Modelling, Integrated Assessment, Water Resources Allocation, Climate Change*

SEVA: A non-linear mathematical framework for climate change vulnerability assessment

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Abstract: Assessing vulnerability to climate change allows policymakers to prioritize policy interventions and better allocate resources. Climate Change Vulnerability Assessment (CCVA) can play an important role in developing long-term environmental and infrastructure plans. Typically, a CCVA exercise combines knowledge from multiple disciplines (e.g., climate science, public health, social science, infrastructure systems, economics) in order to build models of the vulnerability to a climate-related stress of a valued attribute (e.g., health, prosperity, security) of a socio ecological system (SES) (e.g., local government area, councils, counties). In indicator-based vulnerability assessments (IBVA), indicators are adopted as proxy measures of processes generating vulnerability. However, some of the widely recognized challenges of IBVA have been the absence of a mathematically robust framework that can combine information from different knowledge domains, while taking into account the partial compensation of loss/gain between indicators, non-linearities, and tipping points. In one of our previous papers we showed that even though their goals are fundamentally different, Multi-Criteria Decision Analysis (MCDA) and IBVA have the same structural features. Hence, we proposed an aggregation framework for IBVA using insights from the older and more mature field of MCDA (El-Zein and Tonmoy, 2013a) . The goal of this paper is to extend this framework in order to define and deal with non-linear relationships and threshold effects commonly occurring in IBVA.

We first identify different sources of non-linearity present in the context of IBVA. We distinguish between a *fundamental nonlinearity* (dependence of vulnerability on magnitude of stress), a *deductive nonlinearity* (where a deductive or mechanistic model is required to identify the relationship between a set of indicators and vulnerability) and an *intuitive nonlinearity* (where the same relationship is characterized as non-linear through inductive arguments by stakeholders and/or experts). Second, we build a new framework called the Sydney Environmental Vulnerability Assessment (SEVA) by introducing harm as a concept that replaces or mediates the relationship between the indicator and the vulnerability it represents. Harm can be conceived of as a more concrete, less abstract form of vulnerability that is more amenable to quantification. A harm criterion then, like an indicator, acts as a proxy for a process generating vulnerability. However, a harm criterion allows us to achieve two key objectives: a) to relax the conditions concerning linearity, and b) to separate deductive and intuitive nonlinearities in order to better deal with both of them.

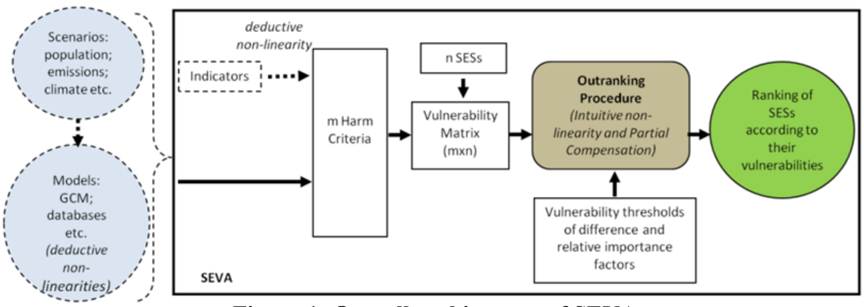

Figure 1: Overall architecture of SEVA

SEVA conducts aggregation of harm criteria using an outranking framework. In a previous paper, we showed that outranking methods, developed in decision science, are better suited to IBVA because their theoretical requirements are less stringent than multi-attribute utility theory (MAUT) approaches, and do not require perfect knowledge of preference structures (El-Zein and Tonmoy, 2013a). Outranking procedures are especially powerful in dealing with partial compensation and fuzzy relationships and, through SEVA (Figure 1), we extend the capability of an outranking procedure (ELECTRE III) to deal with the nonlinearities defined above. We simulate various combinations of nonlinearities and partial compensation through specific definitions of *thresholds of differences* (which are basic parameters of fuzziness in outranking algorithms). We demonstrate the use of SEVA by applying it to a hypothetical model of vulnerability of beach residents to sea level rise and its associated processes.

***Keywords**:* *vulnerability assessment, climate change, aggregation, nonlinear, outranking, mathematical framework*

Regional flood estimation in Australia: Application of gene expression programming and artificial neural network techniques

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Abstract: Flood damage can be minimised by ensuring optimum capacity to drainage structures. An underdesign of these structures increases flood damage cost whereas an overdesign incurs unnecessary expenses. The optimum design of water infrastructures depends largely on reliable estimation of design floods which is a flood discharge associated with a given annual exceedance probability. For design flood estimation, the most direct method is flood frequency analysis which requires long period of recorded streamflow data at the site of interest. This is not a feasible option at many locations due to absence or limitation of streamflow records; hence regional flood estimation methods are preferred. Regional flood frequency analysis (RFFA) involves transfer of flood characteristics from gauged to ungauged catchments. The RFFA methods are widely used in practice.

In the past, different RFFA methods have been proposed for Australia, which are based on linear models such as Probabilistic Rational Method (PRM) and index flood method. More recently, regression-based methods have been investigated for Australia, which are also log-linear models. There have been successful application of non-linear models like Artificial Neural Networks (ANN), Gene Expression Programming (GEP) and Fuzzy based methods in hydrology in some other parts of the world. However, there has not been any notable application of these methods in RFFA study in Australia. This paper focuses on the application of the ANN and GEP to regional flood estimation problems in Australia. The GEP approach used in this study provides an integrated mechanism for the identification of the optimum hydrological regions for RFFA study in eastern Australia. In the preliminary study, optimum regions were obtained based on geographic and state boundaries, climatic conditions and catchment attributes. The proposed approaches were applied to 452 stations in the eastern Australia. Results depict that the GEP and ANN approach have a much better generalization capability of RFFA problems. An independent test has shown that the ANN based model provides more accurate flood quantile estimates than the GEP. Overall, the best ANN-based RFFA model is achieved when all the data set of 452 catchments are combined together to form one region, which gives an ANN-based RFFA model with median relative error of 35% to 44% and median ratios (of predicted and observed values) of 0.99 to 1.14.

Keywords: *Flood estimation, artificial neural networks, gene expression modelling, flood frequency, ungauged catchment, quantile regression technique*

Assessing Climate Change Impacts on Antecedent Catchment Wetness and Flooding

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Abstract: The impact of climate change on floods is of key concern. Despite recognition that the intensity of extreme rainfall is increasing in most regions globally, the impact of this intensification on flood risk is unclear. One of the principal factors is that flood risk is not only determined by the intensity of extreme rainfall, but also by the wetness of the catchment prior to the flood event. This is usually referred to as the antecedent catchment wetness (ACW).

This paper evaluates the relationship between changes in ACW and annual maximum floods using a daily lumped rainfall-runoff model, GR4J, fed by statistically downscaled rainfall. A case study of changes in ACW for the Onkaparinga catchment in South Australia is presented. The flow in the Onkaparinga catchment is ephemeral with all annual maximum floods occurring in winter. The precipitation is downscaled from the CSIRO Mk 3 general circulation model using a nonhomogeneous hidden Markov model for the historical climate (1975 - 2005) and for the A2 and B2 future climate scenarios (2035 - 2065), producing 100 realizations of each. As rainfall extremes were under predicted the downscaled rainfall was bias-corrected using empirical quantile mapping. Changes between the simulated historical and future ACW are evaluated by simulating runoff for the historical climate and future climate scenarios. For this analysis GR4J's production store levels were taken as indicative of catchment wetness. ACW was determined by extracting the catchment wetness on the day prior to the annual maximum flood from the time series produce by GR4J. Also, as climate projections indicate increases in evapotranspiration (ET) are likely under a future climate, current ET data was scaled by up to 25% to assess sensitivity to ET changes.

It was observed that high average recurrence interval (ARI) floods resulted from ACW with high ARIs for all explored ET cases and time periods. Ratios of the future to the current climate of the simulated floods or ACW were calculated for each ARI. Figure 1 illustrates the variation in median ratio for both ACW and annual maximum floods for B2 scenario replicates. Median changes in ACW with high ARIs are minimal ranging between -2 and 3% for all ET cases. These median changes are not statistically significant. However, more distinct changes in high ARI floods are seen, ranging between -8 and 10%. Thus changes in these floods can be related to changes in extreme rainfall independently of changes in ACW and ET. Conversely, large changes in distributions of ACW and floods are seen for low ARIs, increasing with increasing ET. Thus low ARI floods and ACW are sensitive to changing ET. The practical implications of this are; when estimating floods under a future climate for a catchment with similar hydrology to Onkaparinga, for high ARI (> 10 years) floods, the change in extreme rainfall is the key component, with ACW changes playing only a minor role. For lower ARI (< 10 years) floods, the impact of changes to the ACW distribution is increasingly important. This implies that for high ARI floods, only the change in extreme rainfall needs to be considered and current ACW values may be appropriate. Further work on wider variety of catchments and hydrological models is needed to test the generality of these conclusions.

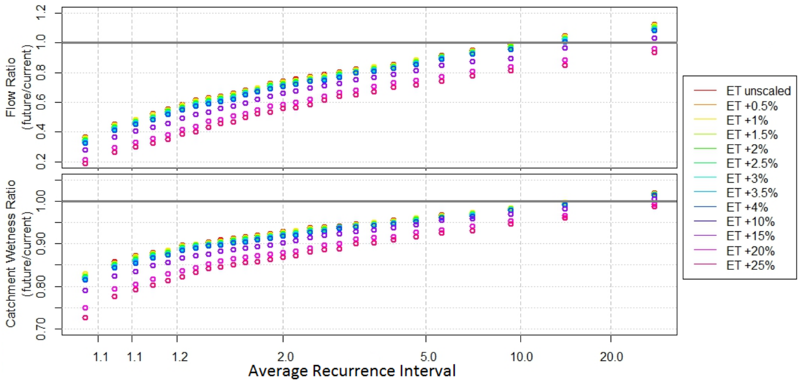

Figure 1. Flood and antecedent catchment wetness change ratios for the B2 scenario for a range of ET scalings.

Keywords: *Climate change, antecedent catchment wetness, floods*

Application of Monte Carlo Simulation Technique to Design Flood Estimation: A case study for the Orara River catchment in New South Wales

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Abstract: Design of water infrastructure projects such as bridge and embankment require design flood estimation. Ideally, design flood estimation is done using at-site flood frequency analysis. However, in many cases, the flood estimation needs to be done at ungauged locations. Methods often adopted for this task such as index flood, rational and regression-based methods are limited to peak flow estimation. As a result, these methods are not suitable in the estimation of complete streamflow hydrograph. At present, Design Event Approach (DEA) is the method currently recommended in Australia for the estimation of design flood hydrograph. However, this method has serious limitations as it treats the rainfall depth as the only random variable in modelling, while other inputs (e.g. temporal patterns and losses) are kept fixed. Joint Probability Approach (JPA)/Monte Carlo Simulation Technique (MCST) is a holistic approach that has proven to overcome some of the limitations associated with the DEA. However, this method has not been tested to a wider hydrologic and catchment conditions. For wider application of the JPA/MCST, one needs readily available regional design data such as stochastic rainfall duration, temporal patterns and losses in the rainfall runoff modelling. This paper presents regionalisation of the model inputs/parameters (i.e. rainfall duration, inter-event duration, intensity-frequency-duration, temporal patterns, initial loss, continuing loss and runoff routing model storage delay parameter) to the JPA/MCST for the State of New South Wales (NSW).

This study uses data from 86 pluviograph stations and six catchments from NSW to regionalise the distributions of the input variables and runoff routing model storage delay parameter for the application with the JPA/MCST. A test catchment (the Orara River) is used to test the applicability of the regionalised JPA/MCST in flood estimation.

In this study, complete storm events are selected from the selected pluviograph stations. The selected complete storms are then analysed to derive rainfall complete storm duration (D_{CS}), inter-event duration (IED), intensity-frequency-duration (IFD) data and temporal patterns (TP). In addition, concurrent rainfall and streamflow events data are used to derive values of initial loss (IL), continuing loss (CL) and runoff routing model storage delay parameter (k). The D_{CS}, IED, IL, CL and k data are described by probability distributions, in that three goodness-of-fit tests are applied (i.e. the Chi-Squared test, Kolmogorov-Smirnov test and Anderson-Darling test). The fitted probability distributions for these variables are then used to specify the regional stochastic inputs in the application of JPA/MCST in NSW State.

The spatial proximity method is adopted in the regionalisation of the D_{CS}, IED, IFD and TP data, i.e. a distribution at an arbitrary location is determined by using a number of nearby gauged stations' data. To regionalise D_{CS}, IED and IFD, data from pluviograph stations within 30 km from the catchments' centre were considered with the aid of inverse distance weighted averaging method. For the TP data regionalisation, a maximum of 20 nearest pluviograph stations within 200 km were used. Here, it has been found that D_{CS}, IED, IL and k data can be approximated by gamma distribution and the CL data by exponential distribution.

These regionalised stochastic inputs have been applied to the Orara River catchment in NSW. The derived flood frequency curves from the regionalised JPA/MCST method have been compared with the results from the DEA; it has been found the adopted method showed better results than the DEA generally. However, it should also be noted here that the applicability of the regionalised JPA/MCST needs to be tested to some additional catchments, which is being carried out as part of the on-going research and will be reported in future publications. Although, the method and design data developed in this study are primarily applicable to the eastern part of NSW, it can be adapted to other States of Australia and other countries.

Keywords: *Joint Probability Approach, Monte Carlo simulation, Design Event Approach, regional design data, rainfall runoff modelling*

A simple storage based floodplain inundation modelling approach in AWRA-R for estimating floodplain fluxes

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Abstract: Floodplains are a critical part of the natural environment and they play important ecological and hydrological roles in river basins. For example, the Murray-Darling Basin (MDB) in Australia has over 30,000 floodplains and wetlands, which provide a range of ecological benefits.

The Australian Water Resources Assessment (AWRA), built as part of the Water Information Research and Development Alliance (WIRADA) between CSIRO and the Bureau of Meteorology (BoM), is designed to support BoM in the production of the National Water Accounts and AWRA reports, which provides an overview of water fluxes and storages at the national scale. AWRA-R, one of the three components of the AWRA system, focuses on river systems including fluxes and storages in floodplains. A simple storage based approach was designed within the AWRA-R modelling platform to model floodplain fluxes and storages. During any flood event, flow in a river reach within a floodplain is partitioned into two components, in-stream and overbank flow, based on the in-stream capacity. A flood volume-area relationship, derived from MODIS-SRTM based inundation volume-area time series, is used to estimate flooded area for the overbank flow. The losses due to evaporation and groundwater recharge from the floodplain are calculated using the estimated flooded area.

The model was implemented in all floodplain river reaches across the MDB. The inundation modelling parameters were calibrated as part of the step-wise calibration of the AWRA-R model. The model has produced the daily time series of floodplain stores and fluxes. The mass-balance analysis shows that the long term mass-balance error was negligible for all floodplain reaches.

Keywords: *Flood inundation modelling, River System model, Wetlands, Murray-Darling Basin, Water Resources Planning, Water Resources Accounting*

Using spatial modelling to develop flood risk and climate adaptation capacity metrics for assessing urban community and critical electricity infrastructure vulnerability

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Abstract: The aim of this study was to develop a new spatially-explicit analytical approach for urban flood risk assessment and generation of climate adaptation capacity metrics for vulnerability assessment of critical electricity infrastructure.

Using the January 2011 flood in Queensland (Australia) with the core suburbs of Brisbane City as the study area, this study addressed the sufficiency of indicating variables and their suitability for climate risk modelling. A range of geographical variables were analysed using a) high resolution digital elevation modelling and urban morphological characterisation with 3D analysis, b) spatial analysis with fuzzy logic, c) proximity analysis, d) quadrat analysis, e) collect events analysis, f) geospatial autocorrelation techniques with global Moran's I and Anselin Local Moran's I, and g) hot spot analysis. The issue on the sufficiency of indicating variables was addressed using the topological cluster analysis of a 2-dimension self-organising neural network (SONN) structured with 100 neurons and trained by 200 epochs. Furthermore, the suitability of flood risk modelling was addressed by aggregating the indicating variables with weighted overlay and modified fuzzy gamma overlay operations using Bayesian joint conditional probability. Variable weights were assigned to address the limitations of normative (equal weights) and deductive (expert judgment) approaches.

The outputs of the topological cluster analysis showed that 15 out of 22 indicating variables were found sufficient to spatially model the flood risk and climate adaptation capacity metrics. The analyses showed that 214 ha (9%) and 255 ha (11%) of the study area were very highly impacted by the January 2011 flood as indicated by the very high flood risk metrics and the very low adaptation capacity metrics, respectively. In the electricity network vulnerability assessment, a total count of 72 critical assets (zone supply substations, high voltage switching sites, and pole transformer sites) were found highly vulnerable to flood hazard. The flood damage disrupted electricity supply along 627 km and 212 km of transmission lines on the north eastern to south western and south eastern sides of the study area, respectively.

The newly developed spatially-explicit analytical technique, identified in this study as the *flood risk-adaptation capacity index/metrics-adaptation strategies (FRACIAS) linkage model*, will allow the integration of flood risk and climate adaptation assessments which have been treated separately in the past. As technical support to the Queensland Floods Commission of Inquiry (QFCI) recommendations, this study also provides a tool and identifies adaptation strategies to enable urban communities and the power industry to better prepare and mitigate future flood events.

The tool can also be used to assess the physical vulnerability of other critical assets (e.g. water supply, sewerage, communication, stormwater, roads and rails) to flooding.

Keywords: *Flood risk assessment, climate adaptation capacity, geospatial autocorrelation, Bayesian joint conditional probability, self-organising neural network*

Long Term Water Demand Forecasting: Use of Monte Carlo Cross Validation for the Best Model Selection

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Abstract: Selection and validation of any statistical models are very crucial in modelling and forecasting problems. In multiple regression analysis of forecasting long term water demand, various models are developed with a variety of predictor variables. Moreover, multiple regression models can take different forms such as linear, semi-log and log-log. In this paper, an effective but simple procedure named Monte Carlo cross validation (MCCV) is applied and compared to the most widely used leave-one-out validation (LOO) to select the best multiple regression model to forecast water demand. Unlike LOO validation, MCCV leaves out a major part of the sample during validation. Both methods are also used for estimating the prediction ability of the selected model on future samples. The advantage of MCCV is that it can reduce the risk of over fitting the model by avoiding an unnecessary large model. In this paper, MCCV and LOO are applied to the water demand data set for the Blue Mountains, NSW in Australia for single dwelling residential sector. The results show that MCCV has the ability to select an appropriate water demand forecasting model. It is also found that, MCCV assesses the prediction ability of the selected model with a higher degree of accuracy. Furthermore, the model selected by MCCV provides less uncertainty when forecasting long term water demand.

Keywords: *Multiple regression analysis, Monte Carlo cross validation, Water demand, Forecasting, Blue Mountains*

Trend analysis of flood data in Australia: A case study for Victoria

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Abstract: The possible impact of climate change on water resources management has received a great deal of attention from scientists all over the world. It has been noted that climate change will have a significant impact on various aspects of hydrologic cycle such as rainfall and floods. Due to climate change, the flood data can no longer be assumed stationary. Previous studies have shown that about 15% of Australian stream gauging stations show trends in annual maximum flood data, mostly downward in the south & south-east regions and upward in the northern region. These studies were based on the flood data till 2005 as part of Australian Rainfall and Runoff Revision Project 5. In this study, an updated database has been prepared for the annual maximum floods covering till year 2011 for the state of Victoria. This updated database is then used in this paper to identify trends in annual maximum flood series data using Mann-Kendall test. It has been found that 26% of the selected stations exhibit a downward trend at 5% level of significance, and none show an upward trend.

The trend analysis was also repeated for 10% and 1% significance levels as well. Here, 60 stations show trends (i.e. 39% of the stations) at 10% level of significance and 14 stations show trends (i.e. 9% of the stations) at 1% level of significance. In all cases, the demonstrated trends are much higher than that would have been shown by mere sampling variability. Furthermore, no noticeable relationship between trends and catchment areas is identified. The reason behind these trends is being examined, and will be reported in future publications.

Keywords: *Trend, Australian Rainfall and Runoff, annual maximum flood series, non-parametric test, floods.*

LUCICAT Model as a river flow forecasting tool: an experiment with Fitzroy River catchment of Western Australia

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Abstract: Early warnings of river flow, particularly high flow, allow individuals, communities and industries to respond in an appropriate manner to reduce the probability of suffering, personal injury, death and economic loss. To increase the lead time of river forecasting, major river forecasting centers across the world are using numerical weather predictions for continuous river flow forecasting. Low flow forecasting is also important to many stakeholders like water resources managers and farmers. The Land Use Change Incorporated Catchment (LUCICAT) model is a distributed lumped conceptual model which is widely used for water resources assessment in most of the Western Australian catchments and few eastern state catchments. This study aims at investigating LUCICAT model's potential in continuous river flow forecasting. The experiment is carried out in Fitzroy River catchment of Western Australia for simulating both high and low flow in hourly time step with an emphasis towards high flow. The model consists of two components: (a) the daily Water Balance Model (WBM) and (b) the Flood module. The daily WBM was calibrated for the period of 1961-2010 using observed daily stream flow data at 11 gauging stations against a set of calibration criteria which were (i) joint plot of observed and simulated daily flow series, (ii) scatter plot of monthly and annual flow, (iii) flow-period Error Index, (iv) Nash-Sutcliffe Efficiency, (v) Explained variance, (vi) Correlation Coefficient, (vii) overall water balance and (viii) flow duration curves. The Flood module was calibrated for 2006 flow event using observed hourly discharge and stage height data. The Flood module takes catchment initial condition from the daily WBM at a particular date from which the Flood module start running in hourly time step. For calibrating the Flood module, calibrated set of parameter from the daily WBM were taken and three parameters were adjusted which were (i) Dry water store soil moisture exponent, (ii) Wet water store soil moisture exponent and (iii) Lateral conductivity wet store (mm/day). Six separate flow events have been simulated in hourly time step to test following three hypotheses: (i) a single set of parameters is valid for the whole catchment, (ii) a single set of parameters is valid for different flood events, and (iii) no change of parameter is required during operational prediction. Findings suggest that the hypotheses are valid and the model has fairly good potential in simulating continuous river flow, both high and low flow. Hence, once the model is calibrated for a particular catchment, it can be used for water resources assessment and continuous river flow forecasting.

Keywords: *LUCICAT, Flood, Fitzroy River catchment, Continuous flow, Forecasting*

Hydrodynamic modelling of potential impacts of climate change on hydrological connectivity of floodplain wetland

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Abstract: Hydrological connectivity between wetlands and the main streams is a major determinant of the ecological condition of floodplain systems. This paper describes the application of MIKE 21 hydrodynamic (HD) modelling tool to assess the hydrological connectivity between floodplain wetlands and main rivers in the Flinders catchment in north Queensland, Australia. The SRTM (Shuttle Radar Topography Mission) derived 30 m DEM was used to reproduce floodplain topography and stream networks in the HD model. Land surface roughness parameters were estimated using a land use map derived from remotely sensed data. The model was calibrated using stream gauge records (stage heights) on the floodplain and inundation maps derived from a combination of MODIS imagery. An algorithm was developed to combine the HD model results with floodplain topology to quantify flood inundation and connectivity between wetlands and rivers. The connectivity of 18 off-stream wetlands, which are considered ecologically important to fish population, was quantified for 3 different floods. The impacts of climate change on connectivity to individual wetland were assessed for Cdry (dry climate), Cwet (wet climate) and SLR (sea level rise) conditions. The results reveal that connectivity will decrease under dry climate and increase under wet climate while impact of SLR is minimal. The information could be useful to future studies on movement and recruitment patterns of aquatic biota during floods.

Keywords: *Hydrological connectivity, wetland, hydrodynamic modelling, MODIS, ecology*

Regional Flood Modelling in the New Australian Rainfall and Runoff

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Abstract: This paper presents the regional flood estimation model being developed for the 4th edition of Australian Rainfall and Runoff (ARR). This covers the basic steps in the adopted modelling framework i.e. data collation, formation of regions, model form, and estimation of the parameters of the model. The adopted modeling framework revolves around the principles of reduction of uncertainty and the best possible use of the regional data by the reduction of the regional heterogeneity to enhance the accuracy of at-site design flood estimation. The ARR regional flood estimation model uses a Bayesian generalised least squares regression-based approach in the data-rich regions of Australia that consists of 619 stations. In the formation of the regions, it divides Australia into a number of regions. A region-of-influence approach is adopted to form regions where there are over 50 stations in the region. It also adopts a parameter regression technique where three parameters of the Log Pearson Type 3 distribution are regionalized. A Monte Carlo simulation technique is adopted to estimate the model uncertainty. The RFFA model is being re-calibrated with the new IFD data and the most up-to-date streamflow records and is expected to be released by Dec 2013.

Keywords: *Regional floods, ungauged catchments, Australian Rainfall and Runoff, GLS regression*

Challenges on modelling a large river basin with scarce data: A case study of the Indus upper catchment

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Abstract: Pakistan's unprecedented floods of 2010 highlighted the possible contribution of Indus upper catchment hydrological modeling to flood risk assessment. However, this modeling is an extremely challenging exercise because of the lack of hydrometeorological data, which are difficult to collect due to the geography of the catchment (the highest point is over 7500 m). Indeed, in the study area (133,300 km^2), there are 24 rain gauges collecting sufficient daily data, which leads to an average area of Thiessen polygons well over (by 10 times) the WMO minimum density network requirements of 250 km^2 for hilly area. The lack of local data for soil and aquifer is another challenge. Despite those limitations, IFAS (Integrated Flood Analysis System) was run to conduct rainfall runoff analysis from the very upstream (in India and China) to Taunsa (midstream Indus in Pakistan). A 30 sec Digital Elevation Model based on GlobalMap Elevation from ISCGM was upscaled to a 5 km grid model. The runoff analysis engine of IFAS is based on a 3-layered spatially distributed tank model. The 24 rain gauges daily precipitation, 9 discharges at river stations, barrages and dams and NCEP reanalyzed latent heat fluxes were considered as input data. Global datasets for land cover (GlobalMap Land cover, ISCGM) and soil textural types and depths (FAO/UNESCO DHSM) were used for parameterization. The upper catchment was divided into sub-basins and calibration conducted independently for each of them. As simulated discharges for mid-lower stream sub-basins were more reasonable than for more upstream sub-basins, parameters calibrated in the mid-lower sub-basins were applied to the upstream ones. Then, the calibration process was conducted for three flood events (1988, 1997 and 2010). Finally, in order to validate the parameters and the model, Nash-Sutcliff efficiencies, E_{NS}, were calculated for discharges simulated for three other flood events (1992, 1994 and 2012). In average, E_{NS} were over 0.80 at seven river stations and the model was considered well-calibrated.

Keywords: *Flood, hydrological modeling, large river basin, Indus, Pakistan, IFAS (Integrated Flood Analysis System).*

Estimation of water surface elevation on inundated area using satellite based information

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Abstract: Recently, water-related disasters have become frequent in the globe; e.g., the large flooding in 2011 at Chao Phraya Basin in Thailand caused considerable damage. Not to repeat such a catastrophe, a risk reduction strategy needs to be considered with a comprehensive risk assessment as well as appropriate information. Also the climate change is one of the important factors that need to be included in the risk reduction strategy. Therefore, actual phenomena should be analyzed based on the past events. Sooner or later, numerical estimation should be conducted with verifying the past event. Therefore, as the first step of constructing the risk reduction strategy, the most fundamental information is water surface elevations on inundated area at the points of interest. This paper aims to obtain the water surface elevation based on observed value.

The present study describes processes to estimate the water surface elevation on inundated area applying satellite based information. As targeted area, Lower Mekong Basin (LMB), which is frequently flooded area, was selected. Firstly, eight days composite data set of Moderate Resolution Imaging Spectrometer (MODIS) was applied for obtaining inundated area with calculating Modified Land Surface Water Index (MLSWI). This is the index to identifying water bodies, which is originally proposed by the authors. MLSWI from 2002 to 2012 in the part of LMB was well examined, flood types were then classified to illustrate flood phenomena. Secondary, with combining Digital Surface Model (DSM) obtained from the Shuttle Radar Topography Mission (SRTM) as well as the inundated area with MLSWI, horizontal distribution of the water surface elevation (WSE) with the selected types of flooding was estimated. Tuning up of the MLSWI with local gauge information is necessary for better estimation. Finally, an appropriate water surface profile, which conforms to hydraulic judgment, was obtained.

Keywords: *Inundated area, Water surface elevation, Satellite information, Lower Mekong Basin*

Changes in flow threshold characteristics due to climate change in a semi-arid region

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Abstract: The rainfall-runoff threshold quantity is fundamental to how often streams flow, and consequently is of significance for stream water dependent ecosystems and for recharge of alluvial aquifers. The pre-threshold behaviour for a natural process usually is very different to the post threshold behaviour. For example, until the threshold is reached a given large rainfall may not produce any runoff, whilst a small additional rainfall can generate large runoff once the threshold is reached. Changes in rainfall and other weather patterns due to future climate change may impact threshold behaviours in catchments. Effects of climate change that are limited to below threshold behaviour may not be as severe as those changes that exceed the threshold. Thus there is a need to keep the threshold characteristics in perspective while assessing future impacts of climate change to understand its effects on runoff initiation and related catchment response. Rainfall thresholds to initiate runoff have never been satisfactorily established for the mostly semi-arid Pilbara region north west of Western Australia. The region has a distinctive climate feature of infrequent but heavy cyclonic rainfall of decreasing intensity as it moves inland and intense but local thunderstorms. It is significantly water limited with the long-term mean annual rainfall of 293 mm and much higher annual potential evapotranspiration close to 3000 mm, and has a large year-to-year rainfall variability ranging from 50 mm to 708 mm.

The effect of climate change on threshold behaviour was examined for three catchments in the Upper Fortescue basin of the eastern Pilbara for a climate change scenario given by the CSIRO Mk 3.6 global climate model for RCP 8.5 scenario and 2050 conditions. This model tends to produce drier scenarios than most GCMs. This was done by comparing the results of threshold analysis using observed data with those from the modelled results. The three catchments used were Marillana Creek (1370 km^2), Weeli Wolli Creek at Tarina (1512 km^2) and at Waterloo Bore (3990 km^2). The long-term average annual rainfall of these catchments is 365, 311 and 330 mm, respectively. For the hydrologic simulation we used the Sacramento model based on its calibration performance.

Flow thresholds were analysed for independent events separated by at least a two-day gap between rainfall events. Rainfall of two days prior to the start of the runoff was considered as part of the event causing rainfall. Analyses of threshold behaviour for yearly time series were also done. Monthly threshold were not analysed due to the splitting of events by change of month.

The modelled results showed the flow behaviour changes significantly under climate change. For event based threshold analysis, the observed rainfall thresholds were 150 mm and 140 mm (Marillana Creek) for two smaller catchments and 100 mm for the largest catchment. The number of events and event size due to climate change was reduced considerably from the observed values in all catchments, making a direct comparison more difficult. Despite this we found that the event based rainfall thresholds for the change to a drier climate remained essentially the same. The yearly threshold for water year starting in October showed characteristics similar to those for the event based threshold. The decrease in the size and number of events was reflected in the yearly values. The corresponding observed yearly thresholds were 400 mm Weeli Wolli Creek at Tarina and between 500 and 700 both for the Marillana Creek and Weeli Wolli Creek at Waterloo Bore. Again, similar to the findings of event based thresholds the yearly threshold value did not change due to the climate change implemented. We concluded that although the frequency and magnitude of runoff generation events are reduced the climate change does appear to not affect the value of threshold rainfall that initiates the runoff in a catchment. Pilbara being a semi-arid region, most of the early runoff is generated by the infiltration excess mechanism. Therefore the reduction of intensity for most of the events leads to the loss of flow initiation opportunity, however runoff generates when the intensity is over the threshold. Thus the climate change affects the loss of intensity but not the threshold of intensity that causes runoff.

Keywords: *Hydrologic threshold, Pilbara, Climate change, Rainfall runoff modelling, Semi-arid*

Climate change impact studies: hydrologic model uncertainty evaluation

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Abstract: The climate change is having great impact on the water resources availability and management all over the World. The hydrologic models forced with the climate change scenarios downscaled from Global Climate Models (GCM) are generally used for climate change impact studies. In this uncertainties arise from: (i) greenhouse gas emission scenarios, (ii) GCM structures, (iii) downscaling method, and (iv) the hydrologic model. The uncertainty from hydrological modeling set up is less compared to other sources like GCM structures and downscaling methods, however it has to be considered especially for impact analysis studies. The physics based models are ideal for the impact analysis studies to account for the future changes in the climate and watershed characteristics. In any model, the optimal parameter values for the calibration period need not perform well in the climate change impact study period (Brigode et al, 2013). This issue can be avoided to some extent by considering the probability distribution function of parameters. The current study used generalized likelihood uncertainty estimator (GLUE) proposed by Beven and Binley (1992), in an iterative manner to derive the actual probability distribution functions of parameters. The proposed methodology employs simulations of the hydrologic model using samples of parameter sets generated by the Latin Hypercube Sampling (LHS). Initially uniform probability distribution functions for the model parameters are assumed in the absence of known probability distribution, for the LHS. The sensitive parameters were identified using Sobol's sensitivity method and the posterior probability distributions of the sensitive parameters are computed using a Bayesian approach. In addition, likelihood values of simulations are used for sizing the parameter range, thereby reducing the predictive uncertainty. The updating of the probability distribution is continued till both the distributions (prior and posterior) converge in successive cycles of simulations. In this study, characteristics of parameters of Soil and Water Assessment Tool (SWAT) are evaluated by deriving the probability distributions functions in Illinois River watershed, USA. All the parameters followed a Beta general distribution, but with varying shape and location parameters as presented in Figure1. Using this derived probability distribution of parameters, ensemble simulations are generated and the prediction interval of the model is estimated.

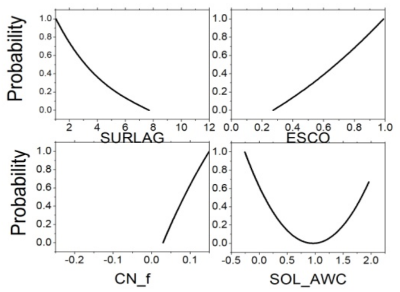

Figure1. Derived Probability distribution of SWAT parameters

Keywords: *Climate change, uncertainty, Physics-based distributed models, Generalized likelihood uncertainty estimation method*

Solar chilled drinking water sourced from thin air: modelling and simulation of a solar powered atmospheric water generator

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Abstract: It is expected that there will be water scarcity in the future under the changing climate. Therefore investigations of innovative and environmentally friendly ways to produce portable water are very much essential. Atmospheric water generators (AWGs) apply vapour compression refrigeration to extract water vapour from the surrounding air. They produce drinking quality water and they require moist air and electricity. The required electricity may be produced by solar photovoltaic (PV) panels. By using solar energy the environmental impacts of an AWG associated with electricity consumption could be substantially reduced. The availability of solar energy and high humidity of air coincide with the drinking water demand. As of today the performance characteristics of stand-alone solar PV powered AWG is unknown. To address this knowledge gap a simulation model of such system has been developed. The model focuses on an individual phenomenon such as solar radiation availability, solar PV electricity output, battery storage, moisture content in the air and heat and mass transfer at the vapour compression refrigeration. The aim of this paper is to present the transient model developed and the simulation results.

Kasaragod district in the state of Kerala, India is selected as the study area. Drinking water availability is a major issue in this district during the months from February to early June. Daily climate variables like temperature, maximum and minimum relative humidity, wind speed and global solar radiation on horizontal plane and wind speed were obtained from a meteorological station located in Kasaragod.

A simulation model has been developed in TRNSYS with the following components: PV modules, Batteries, Regulator, Inverter and Atmospheric Water Generator. By using the model developed the capacity of the AWG, the number PV modules, the capacity of the battery bank required were determined for minimum daily water production of 15 L. The water extraction efficiency of the AWG investigated varies between 5.4% and 9.3% for Kasaragod. The cooling *CCOP*s of the AWG investigated are between 4 and 5, which is better than conventional air-to-air heat pump. Based on the analysis it was concluded that the monthly average daily efficiency is strongly correlated to the monthly average relative humidity of the ambient air. The monthly average daily efficiency is defined as average of all the daily average efficiency for a month. The validation of the simulation model with experiments to enable practical system design optimisations, and the development of control algorithms to obtain better performance by using the validated model are recommended for the future studies.

Keywords: *Drinking water, Solar, Atmospheric water generator*

Modelling to evaluate agricultural adaptation to climate change in southern Australia

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Abstract: An important issue for Australian agriculture is the capacity to adapt to predicted climate change. The International Panel on Climate Change (IPCC) (2009) refers to adaptation as 'adjustment in natural and human systems in response to actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities'. Conceptualizing and evaluating adaptation options in agricultural industries should be conducted at the farming systems level (Rickards et al. (2012), Hayman et al. (2012)) because it is at this level that management decisions are made and financial as well as natural resource impacts will be felt. In particular whole-farm analysis can represent purposeful, goal-seeking systems (Dillon 1976) to assess farmers' profitability and the system's sensitivity to risks such as climate variability and change. The potential of Australian dryland agricultural systems to adapt to climate change with perennial plants was assessed by Farquharson et al. (2013). Perennial plants have deeper rooting systems with improved access to soil moisture, making them better suited to warmer and drier climates. Climate data were generated using Global Circulation Models (GCMs) downscaled to specific locations and corrected for bias (Liu and Zuo 2012). The climate data were used to estimate growth and yield of grain crops, pastures, and an energy-tree crop using process models such as APSIM (McCown et al. (1996)) and GrassGro (Moore et al. (1997). Plant yield and production estimates and economic data (prices of inputs and commodities) were used in bio-economic models (MIDAS (Kingwell and Pannell 1987) and IMAGINE (Abadi and Cooper 2004)) to identify the most profitable land use and the cash flow of options available to growers.

The general result was that adaptation to climate change using new perennial plants shows promise (at least in the short term) of maintaining the economic condition of these dryland farming systems.

While simulation of future conditions is necessary to develop model parameters, we argue that to properly evaluate adaptation a constrained optimising approach is both necessary and sufficient. Adaptation of farm enterprises in a commercial farming system needs to account for the opportunity costs of alternative land uses. To accomplish this, it is necessary to develop bio-economic models with capacity for optimization. Linear Programming (LP) models were used which account for limited or constrained physical, biological and financial resources (e.g. labour, land, credit and time). With the objective function of profit maximization such models explicitly account for opportunity costs faced by decision makers (Paris 1991). The Marginal Value Product (MVP) of each farm activity is the value that the last few hectares contributes to the objective function, and is the basis for the revised farm plan that develops the adapted pattern of farm activities. The adapted farm plan is then used to conduct cash flow analysis which considers the likely risk (income variation) associated with future activities compared to the past.

The use of constrained optimisation is the appropriate way to assess adaptation for purposeful decisions because it accounts for the opportunity costs of farming system decisions - this is the economic evaluation of adaptation. The analysis of farm system components in terms of cash flows considers financial aspects of adaptation. Modelling is essential in assessing future responses to changed external conditions, but constrained optimisation is additionally required to evaluate economic adaptation to climate change in future farming systems.

Keywords: *farming systems, climate change, economic, adaptation, linear programming*

Strategic water management for reliable mine water supply under dynamical climates

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Abstract: Ensuring water security is essential for a broad range of mining activities, where water is required for product washing, dust suppression, drilling, human consumption, and numerous other uses. Sound water management in mining is therefore required to provide a reliable water supply, especially when mine production is rapidly growing and competition of water use with other sectors is increasingly intensifying. However, highly variable climate conditions, leading to excess or deficient water on mining sites, create difficulties in providing reliable water supply to mining operations. It is crucial to include climatic variability in scientific decision-making tools to identify effective mine water management strategies.

Given the high uncertainties in long-term climate predictions, a strategy evaluation approach that can select reliable or robust strategy options under a set of possible future climates is promising. Growing evidences have identified the existence of low-frequency climate signals. However, the statistics of the climate signals are usually poor represented in commonly used climate-foresting models, such as general circulation models. This paper first presents a long-term daily rainfall and evaporation prediction model based on the observation of low-frequency climate signals, such as El Nino Southern Oscillation and Interdecadal Pacific Oscillation. Here, a Markov switching model is built to mimic the regime-like behavior of long-term annual climatic time series. Daily climatic patterns are selected from a historical year that is the most similar to the prediction year. Then a Monte Carlo method is used to create a large number of possible future climate sequences, each of which is a discrete Markov chain and represents a type of possible future climate condition. A future climate sequence can drive a process-based model of mine water use and simulate the impacts of an alternative management strategy. Thus, a set of alternative strategies can be evaluated under the different climate patterns. Finally, under each climate pattern, the performances of alternative strategies are produced. The information allows mine water managers to select reliable management options with desirable performance outcomes under particular climate patterns. The results highlight that the proposed method can identify effective management strategies. The strategies that are evaluated from a large number of climate patterns can lead to greater stakeholder acceptance.

Keywords: *risk assessment, reliable water supply, water resources management, mining, Markov switching model*

An Assessment of Climate Change Impacts on Streamflows in the Musi Catchment, India

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Abstract: The long-term impacts of climate change on water resources are expected to be considerable in Southern India especially in the semi-arid regions. The effects of the changes on precipitation and temperature are expected to alter the hydrology of catchments and ultimately water security. A complicating factor in dealing with climate change from a water resource management perspective in India is the current government policies that promote watershed development (WSD), a policy that promotes the capture of runoff to increase groundwater recharge and irrigation development. In this paper the aim is to quantify the impacts climate change and WSD will have on the hydrologic behavior of the Musi catchment Andhra Pradesh.

Global Climate Model (GCM) predictions of future climate are too coarse for hydrological modelling and fail to account for the most important influence on the monsoon rainfall patterns over India. In order to increase the spatial resolution of the models, a dynamic downscaling approach was used in this research. Three climate simulations corresponding to the IPCC-SRES A1B scenario were downscaled for the period 1961-2098 using “Providing REgional Climates for Impact Studies” (PRECIS) regional climate modelling system. These simulations were based on three versions of the HadCM3 global climate model that showed realistic results for the Indian summer monsoon.

The hydrology of the catchment was modelled using the SWAT hydrologic model. The model was set up for the entire Musi catchment in the Krishna Basin for which the model calibration and validation was carried out at the Osman Sagar and Himayat Sagar gauging stations. Monthly and annual inflows were used to carry out the model calibration. The model calibration and validation yielded Nash-Sutcliffe coefficients ranging between 0.65 and 0.75, which indicate a good model performance.

The downscaled climate data was then used as forcing data in the model to carry out simulations for all three versions of the climate projection data ((Q0, Q1 and Q14). An analysis of flows at different time slices shows that stream flows decline in the near future (2011-40) and then an increasing trend towards the end of the century. Under the Q_1 scenario, annual stream flows show a systematic decline over the period of analysis. The Q_{14} scenario shows an increase in stream flows over the next few decades followed by a decline towards the end of the century. Potential evapotranspiration is predicted to increase for all the climate scenarios. The reservoir component option available in SWAT was used to assess the impact of watershed development structures in the catchment and the analysis shows that stream flows have been declining due to the growth and impact of these structures in the catchment.

Keywords: *Climate Change, hydrology, watershed development*

Adapting agriculture to reduce nutrient loads to the Baltic Sea under future climate and socio-economic conditions – a modeling study in the coastal watershed, Poland

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Abstract: Eutrophication of the Baltic Sea driven predominantly by overloading with nutrients from the Baltic Sea catchment is a major and well recognised environmental problem. Poland is the main country contributing nitrogen (24%) and phosphorus (37%) input to the Baltic Sea and agricultural non-point sources are reported to have the highest share in observed nutrient loads. Little is known about the effects of projected climate and socio-economic changes up to 2050s on nutrient loads discharged to the Baltic Sea by Polish rivers and about the efficiency of agricultural Best Management Practices (BMPs) under future conditions. The SWAT model is applied in the Reda watershed, a small (482 km^2) agricultural coastal watershed in northern Poland to assess the current state of the system, and to quantify effects of future changes under multiple scenarios.

The future scenarios consisted of changes in climate, population and land cover use. The climate projections from the ECHAM5 GCM driven by SRES A1B emission scenario and coupled with RCA3 RCM were acquired from the Swedish Hydrological and Meteorological Institute. Output data from two 50 by 50 km grid points from the RCA3 model overlapping with the Reda watershed were used. The delta change approach was applied to represent the future climate in SWAT. A mean annual temperature increase of 1.3°C and varying from 0.8°C in December to 2.2°C in February was applied. The climate model predicts an annual precipitation increase of 80 mm (by 10%), although it projects a decrease in precipitation in several months. Two agricultural scenarios were developed: one assuming spontaneous development of agriculture (The Business-As-Usual scenario, BAU) and the second one with rapid intensification (Major Shift in Agriculture, MSA) driven by export of agricultural products to the European Union market. Adaptation measures including: (1) fertilization reduction in risk areas, (2) maintaining vegetative cover in winter and spring, (3) buffer zones and (4) constructed wetlands were selected with stakeholder participation and tested in the model. Two possible future climate sequences (Current or ECHAM5-RCA3-SRESA1B climate) combined with three possibilities of future land use (Current, BAU or MSA) produced six unique combinations of model experiments. Such an experimental design allows both studying single effects – climate or land use, and combined effects – climate and land use. In the next step, adaptation measures were implemented into two combined future scenarios.

SWAT was calibrated and validated against daily discharge data at three gauging stations and against bi-monthly total suspended sediment (TSS), N-NO_3 and P-PO_4 loads measured at one station. The model performance in the calibration period was very good for discharge (The Nash-Sutcliffe Efficiency, NSE, equal to 0.75), good for N-NO_3 loads (0.62) and satisfactory for TSS and P-PO_4 load (0.55 and 0.52, respectively). The climate change effect overshadowed the land use change effect under the BAU scenario, in which future N-NO_3 and P-PO_4 loads would increase by 20 and 24%, respectively. In contrast, under the MSA scenario projected N-NO_3 and P-PO_4 loads would increase by 60 and 31%, respectively, which shows that agricultural intensification would not only bring significantly higher crop yields, but also have very negative effect on water quality. Using vegetative cover in winter and spring would be a very efficient measure reducing future P-PO_4 loads below the levels observed at present. However, even the best combination of measures would not help to remediate the negative effects on N-NO_3 loads caused by climate change and agricultural intensification.

Keywords: *Baltic Sea, SWAT, scenario study, agriculture, climate change*

Development of a framework to evaluate the hybrid water supply systems

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Abstract: Centralized water services in many major cities are increasingly being considered to be inadequate in achieving important goals for the urban water sector. It has been argued that new approaches need to be considered in order to cater for additional demand due to increasing population, changing climate, limited resource availability and a desire to protect ecosystems and build more livable cities. It has therefore been argued that providing additional capacity by using only conventional centralized systems is not economically or environmentally the best option. The use of decentralized water supply options such as rainwater tanks; storm water harvesting and reuse; and localized wastewater treatment and reuse in combination with centralized systems can help provide a sustainable solution to address these challenges by reducing the load on fresh water and decreasing the amount of wastewater to receiving environment. It is currently unknown how such technologies impact on the operational performance of the downstream infrastructure and existing treatment processes. For instance, reuse of greywater reduces the wastewater flow and hence there will be more change of solid deposition in the sewerage system. A comprehensive literature review has identified several significant research gaps related to interactions between centralized and decentralized water supply services. One of the prominent gaps is the effects of such hybrid water supply systems (combination of centralized and decentralized systems) on changes in the quantity and quality of wastewater and storm water of the existing system. Therefore, research is necessary to assess the feasibility of their implementation in conjunction with existing centralized systems. Prior to implementing these hybrid water supply systems (WSS), the interaction of these systems with the local environment needs to be understood.

The interactions between centralized and decentralized systems are highly complex. Current practices do not consider the impacts of these systems on the existing infrastructure. Furthermore, implementation of these systems does not consider the external impacts on the rest of the water cycle. This paper proposes a comprehensive framework that focuses on the interactions between decentralized and centralized water supply systems while planning a well integrated hybrid water supply system. Such a system is expected to enhance the performance of water supply in terms of meeting increased water demand with less impact on other urban water cycle components including sewerage and drainage. In addition, it makes it possible to understand, predict and manage the various impacts on the urban water cycle components. However there is a paucity of research in the area of hybrid water supply systems. In order to fulfill this major research gap, this study presents a framework integrated with a number of analytical tools and modeling approaches to evaluate the hybrid water supply systems.

The proposed framework would evaluate the impacts from the implementation of hybrid water supply systems on the quantity and quality of wastewater and storm water in the existing centralized system. This generalized framework coupled with associated models and tools (i.e., water balance modeling, contaminant balance modeling, multi-criteria decision analysis (MCDA), and uncertainty analysis) considers the varying nature of urban areas and is sufficiently generic to analyze the impacts of hybrid water supply systems in any type of urban developments. Hybrid water supply systems can be assessed based on volume and peak flow rates of wastewater and storm water; wastewater and storm water quality; and water supply reliability.

Keywords: *Hybrid water supply systems, Urban water cycle, Evaluation framework*

Modelling the impact of energy intensity on the economic and environmental costs of internally plumbed rainwater tanks systems

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Abstract: Australian capital cities are forecast to face decreased average annual rainfall by 2030 under mid-emissions climate scenarios. With two-thirds of Australia's population already residing in these growing major cities, urban water resources pressure will undoubtedly increase in the years ahead. Methods to augment traditional reservoir based water supply will be required to maintain water security.

Internally plumbed rain water tank systems (IPRWTs), supplying water at a decentralised level, are one potential alternate supply source. Incentive schemes and legislation have seen IPRWTs become increasingly prevalent in metropolitan areas since widespread drought from 2000-2009. For example in Queensland water savings targets were mandated for all newly constructed homes. The most common means of meeting these targets was through the use of IPRWTs, which when installed were required to supply garden irrigation, clothes-washers and cistern flush events.

Studies to date have been focused on maximising potable savings, such that little research has investigated the energy intensity and greenhouse gas emissions associated with the operation of IPRWTs. This is a worthy consideration given that they are typically thought of as green, sustainable solutions.

This paper examines the energy intensity and greenhouse gas cost of IPRWTs under a number of modelled usage scenarios, utilising high-resolution end-use level data from a recently conducted IPRWT monitoring study in South East Queensland. This modelling, facilitated through the use of specialised software, MATLAB and spread-sheet software, has determined the average annual energy consumption of IPRWTs, taking into account the effect of climatic conditions on water consumption. This energy consumption leads to electricity and carbon based costs to homeowners and the general community, which have been quantified at an end-use level.

In the interests of system optimisation, the net economic and environmental impacts of configuration changes to IPRWTs have been considered, such as not plumbing in toilet cisterns. For standard 2.8 person households preliminary evidence indicates that based only on operational costs, more end-uses are preferable, due to higher yields. However, when plumbing and environmental costs are taken into account it has been found that it may be worthwhile to plumb in only the most energy efficient rainwater end-uses (irrigation and clothes washing).

For larger households, or those consuming large volumes of water in regular irrigation, energy intensity of water supply can be significantly lowered by only plumbing in efficient end-uses, while yearly water savings (from avoided mains costs) fall only by a small margin. For retrofitters and new home builders the extra cost incurred when plumbing in toilet cisterns to rainwater supply should be considered. Existing system owners should note the large increase in system energy intensity when small leaks develop from poor maintenance, usually from toilet cisterns, as this can lead to significantly greater economic and environmental costs over the lifetime of a rainwater system and reduce the viability of cistern end-uses.

Keywords: *Rainwater tanks, energy intensity, water supply systems, greenhouse gas emissions*

Assessing the performance of an ensemble approach to rainfall—runoff modelling for prediction of the impact of climate change on streamflow

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Abstract: Climate change over the last four decades has resulted in a significant decline in streamflow in south-west Western Australia, and there is concern for the state of these streams under a future climate. In order to estimate future streamflow, a major exercise was undertaken to simulate the flows under a range of future climate projections. A suite of five rainfall—runoff models was calibrated against observed flow in 106 gauged catchments across the region. The results from weighted means of 31 ensembles, made up of all of the linear additive combinations of the five models, were examined for their ability to reproduce the measured streamflows. The mean of the daily runoff from the Sacramento and IHACRES models consistently resulted in a better model fit than any other combination of the individual models and this 'adopted model' was used to model the runoff under the climate projections. This combination produced the best overall objective function, as determined by the model efficiency of Nash and Sutcliffe (1970) and average bias of less than 2% limit.

Keywords: *Rainfall-runoff modelling, south west Western Australia, ensemble modelling, Sacramento, IHACRES*

Rainfall—runoff model performance suggests a change in flow regime and possible lack of catchment resilience

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Abstract: Climate change over the last four decades has resulted in a significant decline in streamflow in south-west Western Australia. In many streams in the region flows have reduced and perennial streams have become ephemeral. This has been accompanied by a decline in groundwater levels. To study this, a suite of five rainfall—runoff models was calibrated against observed flow in 106 gauged catchments across the region. A linear combination of two models, Sacramento and IHACRES, consistently resulted in a better model fit than any other combination of the individual models and this 'adopted model' was used to study catchment behaviour. In many of the catchments, there was a systematic and pervasive drift in model error during the latter period, indicating a change in state in the catchments that was not captured by the models. An assessment of the suitability of model structure is made on the basis of these results.

Keywords: *Rainfall-runoff modelling, non-stationarity, south-west Western Australia, Sacramento, IHACRES*

Spatio-temporal variation of temperature characteristics over Narmada basin – is the consistent warming trend a possible climate change signal?

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Abstract: The analysis of the high resolution gridded data (1° x 1°) of daily maximum, minimum and mean temperature for the 23 grids covering the Narmada basin has detected varying trends in the upper, middle and lower zones of the basin, based on the 40 years data from 1961-2008. The annual 1-day maximum temperature has been steadily increasing at the rate of 1.10°C/100 yr, but the annual 1-day minimum temperature depicted a much higher rate in increase of 3.20°C/100 yr with significant rising trend at 95% significance level (test statistic: Z = +1.989) based on the non-parametric Mann-Kendall test for detection of trend in time series. The zone-wise temperature variation has been studied for two distinct time periods, each of 20 years viz. 1969-88 and 1989-08. A divergent pattern is observed in minimum daily temperature trends in the various zones of the basin with significant rising trends in the lower zone and no significant trend in the upper zone during both time periods. Also a significant rising trend has been detected in the diurnal temperature range (DTR) in the lower zone during August (Z = +2.21), with no significant trends in other months.

Significant rising trends have been detected in the mean monthly temperatures in the upper and middle zones, with no significant trend in lower zone. Similar pattern of significant rising trend have been detected in mean monthly temperatures during the principal winter (December and January) and summer months (April and May) in upper and middle zones of the basin. However, no significant trend has been detected during the principal monsoon months (July and August) for all the zones. As the basin is located in a semi-arid region and the perennial flows result from the contribution from the soil moisture and groundwater storages, any increase in the maximum and minimum temperatures will change the water availability scenario due to increased water demands from higher consumptive use requirements. To study the water demand scenario in the various zones in the basin, the potential evapotranspiration (PET) has been computed. Significant rising trends in PET were detected in all the zones, during the 1989-08 time slot, which indicates higher crop water requirement from the agriculture sector due to the increased temperatures. The comparison of the zonal annual rainfall (AR) with the actual evapotranspiration (AET) which gives an indication of the supply-demand scenario, has found that the annual AET has been greater than AR in the middle zone on 5 occasions during 1969-88 and subsequently increased to 10 occasions during 1989-08, whereas in the lower zone the AET was greater than AR during most of the years in both time periods. This indicates increased water demands and lower rainwater availability under the changing climate scenario, in the middle and lower zones of Narmada basin, which calls for effective water resources development and management strategies.

Keywords: *Climate change, Trend analysis, Evapotranspiration, Mann-Kendall, Temperature*

Modelling estuarine wetlands under climate change and infrastructure pressure

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Abstract: Estuarine wetlands are an extremely valuable resource in terms of biotic diversity, flood attenuation, storm surge protection, groundwater recharge, filtering of surface flows and carbon sequestration. The survival of these systems depends on a balance between the slope of the land, and the rates of accretion and sea-level rise. Climate change predictions for most of Australia include both an accelerated sea-level rise and an increase on the frequency of extraordinary river floods, which will endanger estuarine wetlands. Furthermore, coastal infrastructure poses an additional constraint on the adaptive capacity of these ecosystems. In recent years a number of numerical models have been developed in order to assess wetland dynamics and to help manage some of these situations.

In this paper we present a wetland evolution model that is based on computed values of hydroperiod and tidal range that drive vegetation preference. Results from a 2D spatially distributed model of wetland dynamics in area E of Kooragang Island (Hunter estuary, NSW) are presented as an example of a system heavily constricted by infrastructure undergoing the effects of sea level rise. Area E presents a vegetation zonation sequence mudflats - mangrove - saltmarsh from the seaward margin and up to the topographic gradient and is compartmentalized by the presence of internal culverts. The model includes a detailed hydrodynamic module (CTSS8), which is able to handle man-made flow controls and spatially varying roughness. The model continually simulates tidal inputs into the wetland and computes annual values of hydroperiod and tidal range to update vegetation distribution based on preference to hydrodynamic conditions of the different vegetation types. It also computes soil accretion and carbon sequestration rates and updates roughness coefficient values according to evolving vegetation types.

In order to further explore the magnitude of flow attenuation due to roughness and its effects on the computation of tidal range and hydroperiod, numerical experiments were carried out simulating floodplain flow on the side of a tidal creek using different roughness values. Even though the values of roughness that produce appreciable changes in hydroperiod and tidal range are relatively high, they are within the range expected for some of the wetland vegetation.

Both applications of the model show that flow attenuation plays a major role in wetland hydrodynamics and that its effects must be considered when predicting wetland evolution under climate change scenarios, particularly in situations where existing infrastructure affects the flow.

Keywords: *Vegetation dynamics, estuarine wetlands, sea-level rise*

Exploring variability in environmental flow metrics for assessing options for farm dam low flow releases

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Abstract: The South Australian Department of Environment, Water and Natural Resources (DEWNR) has undertaken a study to assess the strategic placement of low flow releases (LFR) on farm dams in three Water Resources Areas of the Mount Lofty Ranges, with the purpose of maintaining healthy water dependent ecosystems whilst balancing consumptive demands. Hydrological modelling was undertaken using eWater Source of different LFR installation options based on policies outlined in the draft Water Allocation Plans for the region and optimizing the number and location of LFRs. To facilitate evidence-based decision making as to the optimal set of LFR scenarios that meet environmental flow targets an uncertainty and parameter sensitivity analysis was undertaken.

The aims of the uncertainty analysis were to:

1. Determine the optimal scenario of low-flow release installation options based on the outcomes of the uncertainty and parameter sensitivity analysis.
2. Understand the sensitivity of key farm dam model parameters on the outcomes of each scenario.
3. Determine if certain environmental flow metrics are more sensitive to changes in flow than others.

Hydrological modelling using eWater Source and the Farm Dam Analysis Tool plugin was undertaken to investigate the effects of various LFR placement configurations within selected surface water management zones. Through stakeholder engagement, a range of scenarios was produced to assess the optimal number of LFRs required and the environmental benefit likely to be gained by these options. The relative success of each model scenario was assessed against the environmental water requirements (EWR) for the study regions through the use of environmental flow metrics (EFM), which rely on meeting EWRs related to flow regime, on-farm water usage, dam volumes and low flow release rates.

The EFM framework involves the calculation of 58 different flow metrics, with different pass/fail criteria. As a result of the complexity inherent in the EFM framework, the importance and correlation between environmental flow metrics was investigated using principle component analysis (PCA). A parameter sensitivity analysis using Monte-Carlo methods was conducted on the water use fraction parameter, evaporation loss and dam volume relationship of the farm dam model as these parameters have been identified by previous studies as having a high impact on the uncertainty on model outputs.

From the PCA, five metrics were strongly indicative in differentiating between scenario outcomes. These five metrics generally relate to the occurrence and duration of freshes and high seasonal flows, which are strongly affected by the impoundment of runoff by farm dams during dry periods. The Monte Carlo analysis found that the overall variability in metric pass/fail score for each farm dam parameter was not large, with standard deviations generally between 0.004 – 0.05. The evaporation loss parameter accounted for the largest source of model uncertainty, which is consistent with the literature. Those metrics that exhibited the highest degrees of variability were consistent with the outcomes of the PCA.

The sensitivity in farm dam parameters on scenario outcomes had little impact on the overall selection of the preferred LFR option. However, the variability attributed to certain pass/fail criteria of individual metrics did aid in differentiating between options that produced similar levels of water recovered and performance in meeting environmental flow criteria. The end results of the preferred LFR options are reinforced by the uncertainty analysis, and give support to the project recommendations that will aid in policy decision making.

Keywords: *Uncertainty analysis, Parameter sensitivity, Low flow releases, Environmental water requirements, eWater Source, farm dam modelling*

Multi-response calibration of a rainfall runoff model to assess downstream Environmental Water Requirements

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Abstract: Rainfall – runoff models are often used to inform water resource management and policy, including assessment of the ability to meet environmental water requirements (EWRs) for different management scenarios. Best practice methodologies for developing and calibrating these models when gauged streamflow is available are well documented. However, the process for model development when there are large areas without flow data is less clear. This is the case for the catchments contributing to Lake Hawdon in the South East of South Australia, where the three upstream catchments covering 1009 km^2 have some flow record for calibration, however there is still 600 km^2 downstream of these locations that is not gauged. In this study the functional units approach for regionalisation, built into the Source modelling platform, has been evaluated on the ability to represent the flow response across the three gauges concurrently. It was found that both soil type and land use information was required to capture the difference in rainfall-runoff relationship between the gauges, resulting in four functional units considered. A number of rainfall-runoff models were also tested, where it was found that both GR4J and AWBM produced similar calibration statistics in terms of Nash Sutcliffe Efficiency, but AWBM represented the flow duration curve, particularly the low flows, more accurately. The fact that a small number of functional units could represent the variability in flow regime across the catchment provided increased confidence in the simulated streamflow over the whole area contributing to Lake Hawdon, allowing scenario assessment on the ability to meet the lake EWRs to be undertaken.

The scenario assessment undertaken was to investigate diversion rules in the catchment upstream of Lake Hawdon and Robe Lakes, to maximise the volume that could potentially be diverted away from these wetlands towards wetlands to the north of the catchments considered, subject to first meeting the downstream environmental water requirements (EWRs). A regulator on Drain L at the outlet of Lake Hawdon North was considered necessary to meet these EWRs with less water. This project has assessed different scenarios at two upstream locations to identify suitable diversion rates that meet downstream EWRs: the frequency of meeting an Ecologically Ideal Hydrograph (EIH) in Lake Hawdon, as well as maintaining flows to maintain salinity and water levels in the Robe Lakes downstream of Lake Hawdon.

Based on the modelling undertaken, even the largest diversion case considered was expected to meet the EWRs for Lake Hawdon North and the Robe Lakes. However, the system is likely to be best managed in an adaptive way, with the ability to reduce the flow bypassing the Lake Hawdon North regulator when it is desirable to maintain the water level in Lake Hawdon North for longer periods of time (for example, after a number of sequential dry years). It may also be desirable at some times to allow summer baseflows to persist in the system from the upstream diversion points to reduce the salinity in Robe Lakes.

Keywords: *Rainfall-runoff modelling, Hydrology, Environmental Water Requirements, Regionalisation, South Australia*

Groundwater models of the South Australian River Murray for the Basin Salinity Management Strategy: A policy and modelling success

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Abstract: The River Murray in South Australia is prone to high salinity due to inflows of naturally saline groundwater. Land use changes have increased the flow of salt from groundwater to the river, as the watertable has been raised by the clearance of native vegetation and the introduction of irrigation. The Basin Salinity Management Strategy (BSMS) 2001-2015 continued policy measures established under the Salinity and Drainage Strategy (S&DS) 1988 and the Murray-Darling Basin Authority, to manage River Murray salinity, including the Salinity Registers, which record estimates of the salt load impact on the river of land use change and engineering works.

Since the BSMS was agreed, South Australia has developed a suite of groundwater models to provide impact estimates for the Salinity Registers. This has required long-running and close collaboration between state government groundwater modellers and policy officers and also representatives from SA Water and the Murray-Darling Basin Authority. By working together to understand the policy, data information and modelling needs, there has been progressive improvement to each model that has been recognised by independent model reviewers. The work has ensured the state can deliver on a range of obligations under the Murray-Darling Agreement (Schedule 1, *Water Act 2007* (Cth)), South Australia's Strategic Plan (2011), and Water for Good (2010) policies. The groundwater models are updated and reviewed on a five-year rolling basis, ensuring that the models and the Salinity Registers can continue to be refined as scientific understanding, modelling techniques and data acquisition improve.

Keywords: *Salinity, River Murray, Numerical model, Salt Interception Schemes*

Model-based hypothesis testing for decision-making

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Abstract: There is often high uncertainty associated with the predictions made by environmental models. Given this uncertainty, how can models support environmental decision-making? This paper postulates that environmental decision-making can often benefit from being implemented within a risk management framework. The role of the environmental model is then to quantify the uncertainty associated with the potential outcomes of management actions. At the same time, modelling can reduce uncertainty by providing a means to synthesise the available data and test understanding of the system being studied. However, practical considerations mean that both uncertainty quantification and reduction may be difficult to achieve. The information content of site-specific data is often limited. It may not be possible to express all knowledge about a system within the framework of a numerical model. Model structural defects, in particular, may introduce large and unquantifiable errors in model predictions and estimates of predictive uncertainty.

In light of these limitations, this paper endeavours to improve confidence in model outcomes by explicitly applying the scientific method to test predictions. The approach, described as "model-based hypothesis testing", involves posing the failure of a management strategy as a hypothesis and using modelling to attempt to show that failure can be rejected. The method is demonstrated using a model of connected surface and groundwater resources in the Namoi Catchment in New South Wales, Australia. The model contributes to an Integrated Assessment project assessing risks and opportunities for the management of water resources in cotton growing districts.

There are three main steps. The first is to develop and calibrate a model of the environmental system, including management processes. Results of the model calibration and uncertainty assessment provide the modeller with guidance regarding the fit to historical observations and preferred parameter values that the model is entitled to achieve.

The second step is to add to the calibration dataset the hypothesized 'observation' that an undesirable event occurs, despite management action intended to prevent this. The new calibration objective function is comprised of the fit to historical observations, reasonable parameter values and the hypothesised observation. If the model cannot satisfy these three objectives simultaneously, there are two possible conclusions. The first is that the hypothesis of management action failure can be rejected. This increases our confidence in the alternative, which is that the management approach will succeed. However, there is another possible conclusion that cannot be ignored. This is that the original hypothesis regarding the operation of the system, represented by the model structure and underlying assumptions, is incorrect.

The final step is to calculate an indicator of the potential for model structural error. Previous work has demonstrated that the potential for error tends to rise with the extent to which the nature of the model predictions differs from those comprising the data set against which it was calibrated. Based on this, the indicator measures the similarity of conditions encountered when making a prediction to those experienced during calibration. An appropriate indicator metric depends on the behaviour of the system of interest. For the Namoi hydrological model, the potential error indicator is calculated for each prediction time step based on the similarity of antecedent conditions to those occurring in calibration.

Assessment of model structural error is fraught with difficulty. While methods exist that attempt to quantify model structural error, they generally require the use of more than one model. The advantages of the proposed potential error indicator include it identifies model predictions and uncertainty estimates that should be treated with caution; it provides guidance regarding the choice of an appropriate calibration dataset; and it identifies processes that may affect model predictive performance.

Keywords: *Environmental modelling, Decision-making, Uncertainty analysis*

Emulation modelling of salinity dynamics to inform real-time control of water quality in a tropical lake

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Abstract: Emulation modelling has been successfully applied in many environmental applications to reduce large, computationally demanding, process-based models to low order surrogates to be used in place of the original model in problems involving hundreds or thousands of model simulations. Typical examples include optimal planning and management, data assimilation, and sensitivity analysis.

In this study, we describe the identification of a dynamic emulator of a 3D hydrodynamic reservoir model and its subsequent use within a real-time control framework for dam operation. In particular, we adopt a novel data-driven approach that combines the many advantages of data-driven modelling in representing complex, non-linear relationships, but preserves the state-space representation typical of process-based models, which is particularly effective in designing the controller.

The approach is demonstrated on Marina Reservoir, Singapore, which was recently reclaimed to the sea and transformed into a freshwater storage by constructing a barrage. A dynamic emulator of the salinity evolution in a control point near the dam was identified and then used in combination with Model Predictive Control to design the real-time operation of the barrage. Results show that the salinity levels, due to saline intrusion through groundwater seepage, can be dropped to drinking water standards by embedding the emulator in the real-time controller.

Keywords: *Dynamic emulation modelling, data-driven models, process-based models, water reservoirs opera-tion, water management*

Numerical weather models as virtual sensors to data-driven rainfall forecasts in urban catchments

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Abstract: Weather and rainfall forecasts play a key role in operational urban water management, since they allow anticipating the effects of storms and flash floods and initiating alarms in a timely manner. Short-term rainfall forecasts are commonly based on radar nowcasting techniques, which provide high-resolution forecasts limited to a temporal horizon of few hours. Numerical weather models can extend this horizon further in time, but their coarser spatial resolution is often a limit when working on small urban catchments.

In this study, with the purpose of providing long-term and reliable rainfall forecasts in a small urban area, we investigate the use of numerical weather models as *virtual sensors*. The Weather Research and Forecast (WRF) model, fed with real-time Global Forecast System (GFS) data, is implemented for Singapore spatial domain and used to get a time-continuous and spatially-distributed monitoring of the atmospheric processes. The model state variables (e.g. humidity, air temperature, heat exchange etc.) are then processed by an automatic input variable selection algorithm to single out the most relevant variables used by a data-driven model to yield rainfall forecasts at the catchment scale. In this work, we explore different lead times (up to 12 hours) to evaluate the reliability of this approach, as well as different meteorological seasons.

A comparison against the forecasts issued by WRF shows that the prediction accuracy of the input selection-based data-driven models can be improved, especially for long-term predictions (up to 12 hours). Results show that for short lead times (up to 3 hours) the heat flux is the most relevant driver, while for longer lead times a combination of drivers, such as wind and temperature, is selected. Also, such combination varies with the meteorological season. This techniques can thus be adopted to improve the accuracy of rainfall forecasts, although it must be noted that the overall accuracy is still influenced by the underlying numerical model. Indeed, if the numerical weather model does not adequately represent some events (e.g. small-scale convective storms), the selected variables cannot be successfully adopted to yield a rainfall forecast.

Further research will focus on two different aspects. First, the rainfall forecasts will be included in an operational framework, in order to provide long-term inflow predictions to Marina Reservoir and to assess their impact on the barrage operation. Second, the results here discussed will be further investigated, by running the input selection algorithm on a larger datasets and by considering different combinations of lead times and meteorological seasons.

Keywords: *Rainfall forecasts; Input variable selection; Data-driven models; Urban water systems*

Development of a SWAT model in the Yarra River catchment

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Abstract: The degradation of river water quality in Victorian agricultural catchments is of concern. Physics-based models are useful analysis tools to understand diffuse pollution and find solutions through best management practices. However, because of high data requirements and processing, use of these models is limited in many data-poor catchments; for example the Australian catchments where water quality and land use management data are very sparse. Recently, with the advent of computationally efficient computers and GIS software, physics-based models are increasingly being called upon in data-poor regions. SWAT is a promising model for long-term continuous simulations in predominantly agricultural catchments. Limited application of SWAT has been found in Australia for modeling hydrology only. Adoption of SWAT as a tool for predicting land use change impacts on water quality in the Yarra River catchment, Victoria (Australia) is currently being considered. The objective of this paper is to evaluate hydrological behaviour of SWAT model in the agricultural part of the Yarra River catchment for 1990-2008 periods.

The SWAT model requires the following data: digital elevation model (DEM), land use, soil, land use management and daily climate data for driving the model, and streamflow and water quality data for calibrating the model. All these data were collected from local organizations except DEM. Water quality and land use management data were most sparse. All input files for the model were organized and assembled following the guidelines of ArcSWAT interface of the SWAT 2005 version. The study area was delineated into 51 sub-catchments and 431 hydrological response units (HRU), which are unique combinations of land use, soil type and slope. The main methods used in modeling the hydrologic processes were curve number method for runoff estimating, Penman-Monteith method for PET and Muskingum method for channel routing.

SWAT embedded sensitivity and auto-calibration tool was used for sensitivity analysis and calibration. The LH-OAT (Latin-Hypercube and One-factor-At-a-Time) sensitivity analysis method was implemented for all 26 SWAT streamflow parameters. Then the ParaSol (SCE-UA) auto-calibration was performed on 14 most sensitive streamflow parameters. The calibration period 1990-2002 includes both wet and dry period, but the validation period 2003-2008 includes only dry period. Since, a bad representation of baseflow and surface runoff can cause wrong estimates of diffuse pollution loads to the river, baseflow (Q_{bf}) and runoff (Q_r) were also calibrated along with the total flow (Q_t). For runoff and baseflow calibration, manual tuning was done to the baseflow and runoff related parameters. The SWAT model calibration and validation results were evaluated based on the standard guidelines and using the evaluation statistics of Coefficient of Determination (R^2), Nash-Sutcliffe Efficiency (NSE), Percent Bias (PBIAS) and RMSE-observations standard deviation ratio (RSR). In the calibration period, the respective daily, monthly and annual values of the evaluation statistics were for;

- $Q_t \rightarrow R^2$: 0.78, 0.93, 0.96; NSE: 0.77, 0.89, 0.87; PBIAS: 10, 10, 10 and RSR: 0.48, 0.34, 0.36
- $Q_{bf} \rightarrow R^2$: 0.90, 0.93, 0.95; NSE: 0.87, 0.89, 0.88; PBIAS: 6, 6, 6 and RSR: 0.36, 0.33, 0.35
- $Q_r \rightarrow R^2$: 0.50, 0.84, 0.97; NSE: 0.42, 0.80, 0.76; PBIAS: 23, 23, 23 and RSR: 0.76, 0.45, 0.49

In the validation period, the respective daily, monthly and annual values of the evaluation statistics were for;

- $Q_t \rightarrow R^2$: 0.74, 0.82, 0.87; NSE: 0.72, 0.82, 0.81; PBIAS: -3, -3, -3 and RSR: 0.53, 0.43, 0.43
- $Q_{bf} \rightarrow R^2$: 0.79, 0.81, 0.84; NSE: 0.77, 0.79, 0.71; PBIAS: -11, -11, -11 and RSR: 0.48, 0.46, 0.54
- $Q_r \rightarrow R^2$: 0.67, 0.82, 0.87; NSE: 0.53, 0.79, 0.70; PBIAS: 19, 19, 19 and RSR: 0.69, 0.46, 0.55

The model performance statistics showed that the SWAT model performed very well for Q_t, well for Q_{bf} and satisfactory for Q_r. This implies that the SWAT model sufficiently replicated the hydrology of the study area, and can be applied in Australian conditions. In general, the SWAT model overestimated flows in dry years, and underestimated in wet years.

Keywords: *Streamflow, Water quality, SWAT, Yarra River catchment, Australia*

An irrigation model for use in river systems modelling

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Abstract: Irrigation diversion is a key component of the water balance in regulated river systems. However, diversion data are scarce and often require the use of a model to estimate the amount of water diverted. Such models have no need to simulate crop yields and therefore can be simpler in some regards. However irrigation diversion must be able to simulate whole of district behaviour in terms of irrigation diversions, volumes, and soil water balance. Additionally, the model must capture the district/area response to changing water availability. To be useful in the river modelling context the model must also produce daily estimates of diversion and consumptive water use. Considering all these, we have developed an irrigation diversion model which has been presented here.

The model is based upon an FAO crop model approach utilising crop factor curves for various crops. Additionally, soil moisture accounting is used to schedule diversions to irrigation from river allocations, or if available, groundwater licences and on farm storage. Total area planted is determined at four annual decision dates based upon a function varying with available resources. To account for variation in scheduling approaches and soil water holding capacity, a crop irrigation function dependent upon soil moisture and a Gaussian distribution is utilised. The irrigation diversion model has been trialled in association with the Australian Water Resources Assessment project. The model features five calibrated parameters and has been calibrated against observed monthly and daily diversions in irrigation districts in the Murray, Goulburn, Murrumbidgee, Macquarie and Namoi valleys. Good agreement with observed monthly diversion is achieved with Nash Sutcliffe Efficiencies generally within the 0.4 - 0.8 range, and bias less than 10%. The model has significant potential for estimation of river diversions even where there is limited available data with which to calibrate.

Keywords: *Diversion, river system modelling, calibration*

Extending rainfall-runoff models for use in environments with long–term catchment storage and forest cover changes

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Abstract: Here we present a new model algorithm based on the GR4J model (Perrin et al., 2003). The new algorithm features a threshold in the production store and a changed Evaporation calculation that allows more "memory" of catchment state from previous years. Additionally, the new algorithm accepts an input of catchment average Leaf Area Index (LAI) and can modify catchment storage and runoff with changes in forest cover.

The model was tested in catchments of the Darling Range in Western Australia. This environment has experienced both catchment drying and forest disturbance over the past 37 years. The new model algorithm shows improved predictability of run–off in test catchments as well as a better relationship between model catchment storage and observed depth to groundwater.

Keywords: *Non-stationarity, groundwater, runoff, drought, long–term processes, surface water – groundwater connection, models*

EXTENDED ABSTRACT ONLY

A new evaluation framework for input variable selection algorithms used in environmental modelling

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Abstract: Input variable selection (IVS) is an essential step in the development of statistical models and is particularly relevant in environmental modelling, where potential model inputs often consist of time lagged values of various potential input variables. By selecting only those inputs that are both relevant and non-redundant to the prediction model, the generalisation ability of the model is maximised and the underlying phenomenon is easier to interpret due to the reduced dimensionality of the data. While new methods for identifying important model inputs continue to emerge, each has its own advantages and limitations and no one method is best suited to all datasets and purposes. Rigorous evaluation of new and existing input variable selection methods would allow the effectiveness of these algorithms to be properly identified in various circumstances. However, such evaluations are largely neglected due to the lack of guidelines or precedent to facilitate consistent and standardised assessment. Instead, in evaluating the performance of IVS algorithms, current studies tend to:

- select a limited number of data sets which do not adequately encompass the range of properties typical of environmental data (e.g. nonlinear, non-Gaussian, high redundancy);
- select case studies for which the true inputs are unknown and thus do not enable selection accuracy to be properly assessed;
- consider limited assessment criteria, often based on the predictive performance of the constructed model, which is complicated by the chosen functional form of the model and calibration performance;
- lack rigorous implementation (e.g. no repeated experiments), thus preventing the statistical significance of any observed results to be evaluated; and
- only consider a single algorithm without comparison with other algorithms.

Furthermore, there is a lack of uniformity in the selected data sets and criteria by which the performance of the algorithms are assessed. As a result, it is difficult to assess the true utility of different IVS algorithms and hence provide guidance as to which algorithm performs best in different situations.

Here, we propose a new framework for the evaluation of IVS methods which takes into account a wide range of dataset properties that are relevant to real world environmental data and assessment criteria selected to highlight algorithm suitability in different situations of interest. The two main components of the framework consist of (1) a database of partially and fully synthetic benchmark data sets, including 30 replicates of each data set, each with known inputs and exhibiting a range of different properties considered useful for the robust assessment of IVS algorithm performance; and (2) recommended quantitative and qualitative assessment criteria that can be used to evaluate selection accuracy, computational efficiency, scalability and ease of use.

The proposed framework is demonstrated on two state-of-the-art IVS algorithms currently used in environmental modelling studies; namely the Partial Mutual Information (PMI) algorithm and the Iterative Input variable Selection (IIS) algorithm. The main aim at this stage is to demonstrate and fine tune the details of the evaluation framework, rather than to provide a rigorous comparison of these algorithms. Nevertheless, the results indicate interesting differences in the algorithms' performance that have not been identified previously.

Keywords: *Input variable selection, environmental modelling, evaluation framework*

An Equivalent cross-section Framework for Reducing Computational Time in Distributed Hydrologic Modelling

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Abstract: Physically based distributed hydrological models are valuable tools for simulating spatial variability of hydrologic fluxes, i.e. surface runoff, transpiration, soil evaporation, drainage and soil moisture. The application of distributed models is limited due to complex parameterization and long computational time. To reduce the computational time/effort in distributed hydrological modelling, a new approach of modelling over an equivalent cross-section is investigated where topographical and physiographic properties of first-order sub-basins are aggregated to constitute modelling elements. To formulate an equivalent cross-section, a homogenization test is conducted to assess the loss in accuracy when averaging topographic and physiographic variables, i.e. length, slope, soil depth and soil type. The homogenization test indicates that the accuracy lost in weighting the soil type is greatest, therefore it needs to be weighted in a systematic manner to formulate equivalent cross-sections. If the soil type remains the same within the sub-basin, a single equivalent cross-section is formulated for the entire sub-basin. If the soil type follows a specific pattern, i.e. different soil types near the centre of the river, middle of hillslope and ridge line, three equivalent cross-sections (left bank, right bank and head water) are required. If the soil types are complex and do not follow any specific pattern, multiple equivalent cross-sections are required based on the number of soil types. The equivalent cross-sections are formulated for a series of first order sub-basins by implementing different weighting methods of topographic and physiographic variables of landforms within the entire or part of a hillslope. The formulated equivalent cross-sections are then simulated using a 2-dimensional, Richards' equation based distributed hydrological model. The simulated fluxes are multiplied by the weighted area of each equivalent cross-section to calculate the total fluxes from the sub-basins. The simulated fluxes include horizontal flow, transpiration, soil evaporation, deep drainage and soil moisture.

To assess the accuracy of equivalent cross-section approach, the sub-basins are also divided into equally spaced multiple hillslope cross-sections. These cross-sections are simulated in a fully distributed settings using the 2-dimensional, Richards' equation based distributed hydrological model. The simulated fluxes are multiplied by the contributing area of each cross-section to get total fluxes from each sub-basin referred as reference fluxes. The equivalent cross-section approach is investigated for seven first order sub-basins of the McLaughlin catchment of the Snowy River, NSW, Australia, and evaluated in Wagga-Wagga experimental catchment. Our results show that the simulated fluxes using an equivalent cross-section approach are very close to the reference fluxes whereas computational time is reduced of the order of ~4 to ~22 times in comparison to the fully distributed settings. The transpiration and soil evaporation are the dominant fluxes and constitute ~85% of actual rainfall. Overall, the accuracy achieved in dominant fluxes is higher than the other fluxes.

The simulated soil moistures from equivalent cross-section approach are compared with the in-situ soil moisture observations in the Wagga-Wagga experimental catchment in NSW, and results found to be consistent. Our results illustrate that the equivalent cross-section approach reduces the computational time significantly while maintaining the same order of accuracy in predicting the hydrological fluxes. As a result, this approach provides a great potential for implementation of distributed hydrological models at regional scales.

Keywords: *Equivalent cross-section, sub-basin, computational time, distributed hydrological model*

Using parallel computing for efficient large-scale hydrological modelling

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Abstract: Current challenges of understanding and assessing the impact of climate and land use changes on the hydrological resources of large catchments demand for an ever increasing integration of data and process knowledge in hydrological simulation models. While the continuously increasing performance of multi-processor computer environments provides the basis to cope with these models, their structure and underlying software architecture often lag behind and make it difficult to adapt them to parallel processing requirements. Modelling frameworks that represent environmental models as assemblies of simpler process simulation components in a well-structured, descriptive way are therefore promising candidates to provide solutions for this problem.

For the work presented, the Jena Adaptable Modelling System (JAMS) was used as a platform to implement an automated procedure for in-model parallelization. The work focused on timed event systems, i.e. models that simulate environmental processes at discrete space-time and which are widely used in current practice. After examining different options for concurrent processing in such models, a parallelization of spatial sub-models was identified to be the most promising approach. It includes the following steps (Figure 1):

1. partitioning of the model's spatial units into *n* equally sized sub-sets
2. duplication of the model's simulation routines responsible for processing the spatial units (*n* copies)
3. parallel processing of each sub-set by a separate simulation routine

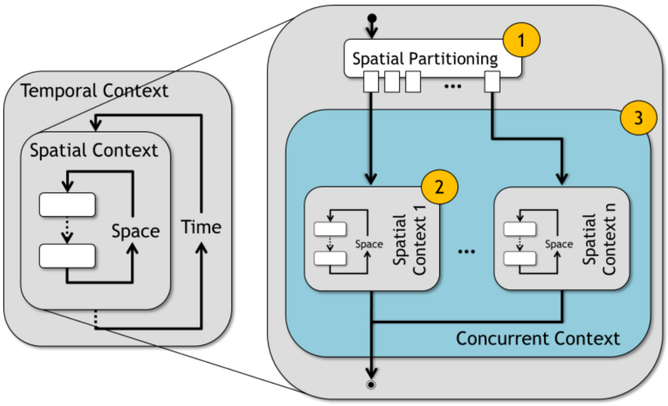

Figure 1. Initial JAMS model (left) and resulting concurrent model (right)

Many hydrological models take into account energy and mass transfers between neighboring spatial units. Therefore, special attention must be given to their partitioning, making sure that interacting units are assigned to the same sub-set.

The parallelization procedure was applied to three different JAMS models: (i) a J2000g water balance model with 57,920 units, (ii) a J2000 hydrological model with 19,422 units, and (iii) a J2000s nutrient transport model with 17,175 units. All of them share a fully distributed spatial representation, but differ in their process representation detail. The hardware used featured 48 processor cores. The results (Figure 2) show that in-model parallelization can significantly boost the runtime performance of complex environmental models, offering room for increased detail both in process representation and spatial input data. However, we also found that the efficiency of parallelization largely depends on the models process representation detail, making concurrent processing especially interesting for models of high process complexity, like e.g. J2000s.

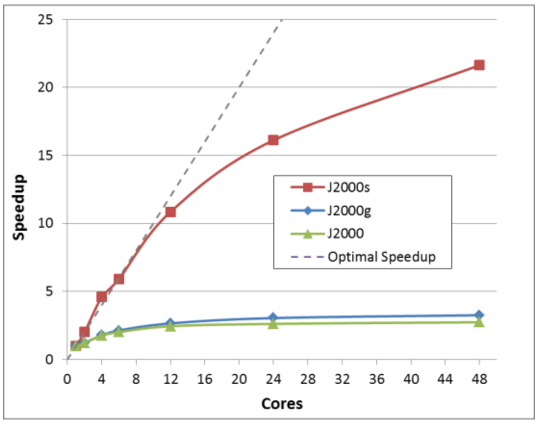

Figure 2. Speedups resulting from model parallelization

Keywords: *Environmental modelling, parallel processing, modelling frameworks*

Reducing propagation of uncertainty in river system modelling by optimal use of streamflow data

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Abstract: Modelling of regulated river systems requires a combination of hydrological components, e.g. rainfall-runoff models, and components dealing with diversion and storage of water. The resulting models often include a large number of calibrated parameters and multiple prediction points. To reduce the dimension of the calibration problem, the modelling domain can be split into river reaches delimited by inflow and outflow gauging stations. When the model is used in predictive mode, e.g. climate change studies, uncertainty generated within the upstream reaches will propagate to downstream reaches and alter the predictions on the lower parts of the model. This study investigates the use of streamflow data to better constrain the calibration of river models. The study is based on the calibration of a river model for a set of six Australian catchments, as part of the Australian Water Resources Assessment (AWRA) framework developed jointly by CSIRO and the Bureau of Meteorology. The river model was calibrated sequentially from upstream to downstream reaches using three different scenarios. In the first scenario, the reaches are calibrated independently using gauged data as inflows to the reach. This option isolates the reaches and minimizes the propagation of uncertainty. However, it leads to sub-optimal parameters when the model is used in predictive mode with no flow data available. In the second scenario, the reach inflows were set to the simulations from upstream reaches. In the third scenario, the inflows are set to a weighted average between gauged inflow and upstream simulations. The model performance was finally assessed in predictive mode. The results from this study suggest that the use of observed inflows leads to a systematic improvement of the performance statistics compared to the use of other inflow data.

Keywords: *River modelling, Streamflow data, model calibration, multisite calibration, GR4J*

Evaluating and Improving Simplified Hydrologic Models for Baseflow and Rainfall-Runoff Estimation Using Distributed Physical Models

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Abstract: Hydrologic models are becoming increasingly important in the planning, design, operation and management of natural and engineered systems. However, development of such models is complicated by the fact that the underlying physical processes are extremely complex and that the observation and measurement of these processes are expensive and difficult. Consequently, simplified models are generally used in practice for purposes such as baseflow estimation and rainfall-runoff prediction. However, it is difficult to provide a rigorous assessment of how well such simplified models perform under a range of catchment characteristics (e.g. catchment area, soil type, slope) and hydrological inputs (e.g. rainfall, evaporation) and how well they are able to capture the underlying physical processes. In addition, without such assessments, it is difficult to change model structure and parameterization in order to improve the models' predictive capability and the ability to better represent physical processes.

In order to address these shortcomings, a framework for using fully coupled surface-groundwater models to assess and improve the performance of simplified hydrologic models under a range of physical catchment characteristics and hydrological inputs is developed. The underlying premise of the frameworks is that fully integrated surface water/groundwater (SW/GW) models are able to provide the best possible approximation to the physical processes of water flow within catchments and can therefore be used as a benchmark against which the performance of these simplified models can be assessed for a variety of physical catchment characteristics and hydrological inputs. In this sense, the fully integrated models act as a virtual laboratory for assessing the performance of simplified hydrological models under a range of conditions. While it is acknowledged that such virtual laboratories are a simplified representation of reality, they provide a first step towards a more rigorous evaluation of commonly used models. It should be noted that use of virtual laboratories will not provide conclusive evidence that particular simplified models are able to represent reality, but they will be able to highlight inadequacies of simplified models in terms of being unable to represent certain hydrological processes explicitly.

The proposed framework is applied to three commonly used baseflow filters (the Lyne and Hollick, Boughton 2-parameter and Eckhart filters) and one commonly used conceptual rainfall-runoff model (the Australian Water Balance Model) for a synthetic catchment with a large range of catchment characteristics (catchment area, hill slope, channel slope, aspect ratio, K_s, and van Genuchten parameters α and β) and hydrological inputs (rainfall and evapotranspiration for Adelaide, Brisbane, Darwin, Melbourne and Sydney). Hydrogeosphere (HGS) is used as the virtual laboratory.

In relation to the baseflow filters, the results show that the ability of the filters to match the baseflow predicted by HGS varies with catchment properties and can be improved if values of the filter parameters are adjusted based on catchment characteristics. With respect to the Australian Water Balance Model, the results show that consideration of the internal model dynamics during the calibration processes is able to improve representation of baseflow and quickflow. Overall, the results indicate that the knowledge gained from detailed numerical experiments has the potential to improve the performance of commonly used simplified hydrological models.

Keywords: *Integrated surface water / groundwater models, Hydrogeosphere, Virtual laboratory, Recursive digital filters, Conceptual rainfall runoff model*

Assimilation of SMOS data for improving surface water management

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Abstract: The overall objective of this research is to demonstrate the potential use of Soil Moisture Ocean Salinity (SMOS) data for operational surface water management. A particular focus is made on discharge predictions. Therefore, two large-scale basins have been identified. For these basins, radio frequency interference does not present a problem, the land cover allows for accurate soil moisture retrieval, floods occur relatively frequently, and initial catchment storage is known to be important in discharge generation. These basins are the Upper Mississipi in the USA and the Murray Darling Basin in Australia. The Variable Infiltration Capacity (VIC) model has been calibrated for both basins using available discharge records.

The first part of the paper focuses on soil moisture assimilation. A data assimilation algorithm has been developed, in which the mismatch between the spatial resolutions of the model grid (10 km) and the satellite observations (25 km) have been taken into account. This is performed through the observation operator, which also takes into account the spatial weighting function (the average antenna pattern) in the determination of the large scale average. Bias between the soil moisture observations and the model predictions has been removed through cdf-matching. A spatial downscaling procedure has also been applied, in which the SMOS products are interpolated to the VIC grid prior to assimilation. An offline bias removal algorithm is applied in this case. Both approaches (use of the observation operator and prior downscaling) have been thoroughly intercompared. Furthermore, the impact on discharge generation is assessed.

The second part of the paper focuses on brightness temperature assimilation. For this reason, the radiative transfer model (which links the surface soil moisture to the top of atmosphere brightness temperature) has been calibrated, in order to remove the bias between the modeled and observed brightness temperatures. Similar to soil moisture assimilation, the mismatch in scale between the model simulations and the satellite observations has been taken into account through the use of the observation operator, using the antenna pattern as spatial weighting function. The HH and VV brightness temperatures are assimilated. As a first step, all brightness temperatures (angle binned at 6 fixed incidence angles at the surface reference frame) are assimilated. The differences between the results obtained by soil moisture and brightness temperature assimilation are investigated. Finally, only the incidence angle corresponding to the SMAP configuration are retained for assimilation. The advantages and disadvantages of assimilating all available brightness temperatures versus only one single channel are discussed.

Overall, the results of this study are expected to provide a detailed overview of the opportunities and challenges for the use of SMOS observations for operational water management, with a focus on flood prediction.

Keywords: *Data assimilation, downscaling, water management, soil moisture, brightness temperature*

Mapping of flow paths in large, anastomosing arid zone rivers: Cooper Creek, Australia

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Abstract: Anastomosing rivers have moderately to highly sinuous, multiple, interconnected channels which form in low gradient floodplains and there are numerous examples of them in the world, such as rivers in inland Australia. Arid anastomosing rivers of Australia experience high transmission losses during floods and mapping of channels and inundation area can play an important role in quantifying the water lost via evaporation, infiltration or impoundment in wetlands. In this article, two DEM-based stream definition methods and a zero dimensional model were used to map channel patterns in Cooper Creek, Australia. The D8 and D-infinity DEM-based stream definition methods replicate a dendritic structure for the channel map of Cooper Creek which is in contradiction to its anastomosing pattern. In addition, a zero dimensional model in which a hypothetical water surface is overlain to the DEM was run in a large reach of Cooper Creek. The model cannot generate flow patterns along the length of the reach or else inundates a major part of the floodplain and does not illustrate the anastomosing patterns. It is found that the effect of scale, inability of model to calculate realistic water level dropping with flow, DEM inaccuracy and its limitation to capture micro topography are important in accurate mapping of inundation area by zero dimensional models and the model is not suitable for long river reaches. Results suggest that hydrodynamic models, informed by optical remote sensing data and satellite altimetry data, may be the most useful method to simulate and validate the flow routes and inundation area for anastomosing rivers of arid floodplains with high transmission losses.

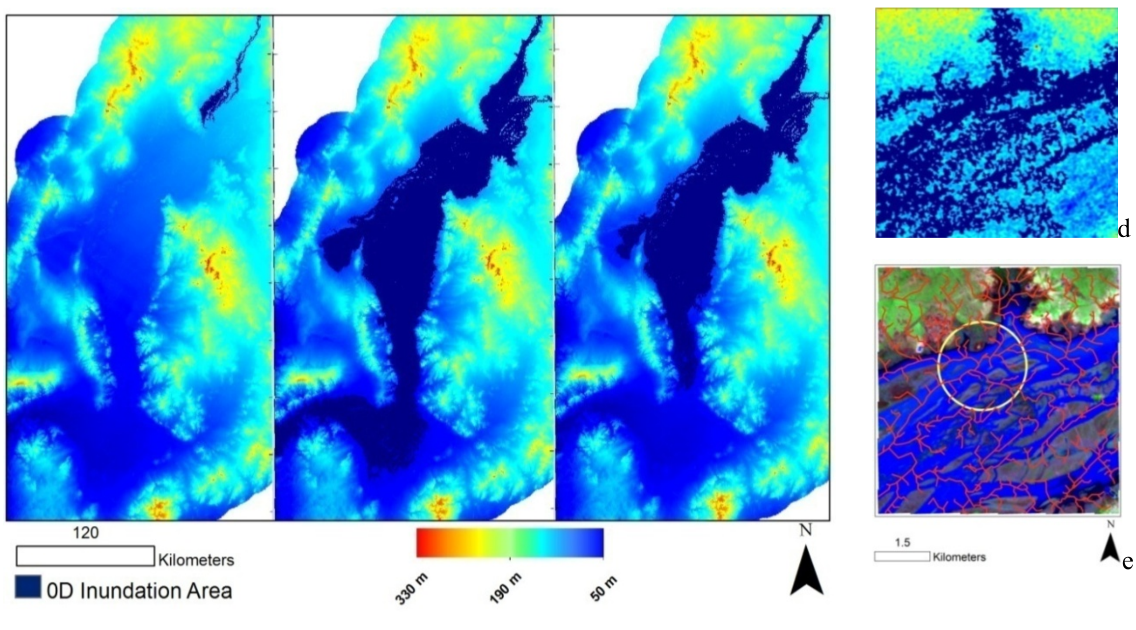

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Figure (a) Flood mapping of Cooper Creek (dark blue) for a small flood with no transmission loss; (b) Medium flood with no transmission loss; (c) Medium flood with 75% reduction of water depth as transmission loss; (d) Inundation map of a small region in Thompson River downstream of Longreach (6.75*6.75 km) modelled by 0-D model (dark blue); (e) Observed coverage for the 1990 flood event, image of Landsat 5 TM (bands 2 (Red), 4 (Green), and 7 (Blue)) and overlaying TAUDEM stream network with only one replication of bifurcation in anastomosing rivers (center of yellow circle).

Keywords: *Anastomosing Rivers, Mapping, ArcHydro, TAUDEM, Cooper Creek*

Optimised Scheduling of Water Supply Schemes

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Abstract:

City West Water (CWW) provides water services to the city and western suburbs of Melbourne, Australia. As water becomes more precious, CWW has embarked on alternate water projects. Among them is the West Werribee Dual Water Supply Scheme (WWDWSS). CWW Engineering Department's Operations Research group built the Mass-Balance Model, MABAL to aid planning and to optimise the operating schedule of water schemes. An early simulation model has been replaced by a linear program to work around supply constraints. At the heart of MABAL, there are 3 models:

- Weather Forecasting: Statistical forecasts 28 days ahead
- Demand Forecasting: Uses weather data, customer numbers, time of year and other factors.
- Linear Programming: Optimises production, subject to supply constraints, to meet forecast demand.

While WWDWSS is under construction, MABAL is being applied to the Ballan Road water supply in Werribee as a pilot. The pilot provides better control of tank levels and makes efficient use of the pump station in response to increasing energy cost. The pilot provides an opportunity to prove the robustness and accuracy of the models and establish communication infrastructure and protocols between the software and the external SCADA devices. The linear programming, helps to overcome the problem of variable demand and supply outages. As a result, scheduling can be optimised. This paper describes the water supply schemes, with focus on the optimization model, the factors that influence the supply and demand sides and the outcomes.

To support the planning of the water supply scheme, MABAL allows the Engineer to define all of the components, the customers and their demand under different weather conditions and to model the operation over different periods. From these simulations the Engineer can change the settings to ensure that the water supply scheme is designed to avoid the need to add potable water to meet demand if the scheme is under-sized. Also, to ensure that the scheme is not over-sized tying up valuable capital. Two configurations exist. One, GMABAL, allows water supply schemes ranging in complexity to be modeled for short periods of time. A second configuration, MABAL-LITE allows complex water supply schemes to be modeled for a much longer number of years while still achieving reasonable runtimes. MABAL has been used to assess the impact of an Aquifer to supplement the above ground storages for the WWDWSS. In particular to answer questions such as: When should above ground storages be doubled in capacity? Can the water supply scheme meet demand with just 2 salt reduction trains and if not when would I need to have a 3rd salt reduction train? MABAL has also been used to determine the impact of an extended Feedwater supply outage of 4 months requested by Melbourne Water.

The development of the linear program model for MABAL has enabled CWW to realize the crucial planning issue of automated planning around future known events and quantity and quality constraints to produce a least cost operational schedule. City West Water has a tool that can be used to model proposed water and alternate water schemes. By running different scenarios through the model, water supply schemes can be planned to meet the critical issues of being configured to be the right-size and delivered at the right-time to balance supply and demand.

Results of the analysis can be included in business cases seeking approval for proposed water supply schemes. Different techniques and levels of generalization can be used to limit or reduce run times to have models solve in business acceptable times.

Operating water supply schemes have quite specific constraints that might be known when planning the scheme or they may be added as a consequence of restrictions imposed by external bodies when gaining approval to proceed with the water supply scheme. CWW has taken the view that operating water supply schemes will have customized models that best deal with each water supply scheme's individual requirements and so that acceptable solving times are achieved.

Keywords: *Optimisation, Forecasting, Water, Scheduling, LINGO*

Optimisation of water scheduling for irrigation using ant colony algorithms

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Abstract: Freshwater is one of the most valuable natural resources in the world, but is limited and unevenly distributed, both spatially and temporally. As water demands of domestic users, industry and the environment are increasing, less water is available for agriculture, especially in regions of water scarcity. As a result, determination of the most appropriate water allocation to different irrigation districts and different types of crops is becoming a serious problem that could affect food security and sustainable socio-economic development. However, irrigation water allocation is a complex problem with a large number of potential alternatives. Therefore, the use of optimisation methods is desirable for determining optimal water allocation schedules at the farm-, sub-basin, and whole-of-basin scales.

In this study, an optimisation framework based on a decision tree graph is developed to maximize the net return of whole irrigation systems at sub-basin/basin scales. This decision tree structure enables schedules to be developed for reservoir(s), irrigation districts and crops simultaneously. Thus, this framework is able to overcome the shortcomings of previous approaches in the literature, which only considered part of an irrigation system or divided the system into independent optimization sub-models with the associated hierarchical resolution issues.

Ant colony optimisation algorithms (ACOAs) are used as the optimization engine in the proposed framework as they enable the sequential nature and dependence structure of the optimal irrigation allocation scheduling problem to be taken into account explicitly. Furthermore, ACOAs are also capable of changing the decision space dynamically, thereby reducing the search-space size during optimisation runs, making it easier to find optimal or near-optimal irrigation allocation schedules.

To test the utility of the proposed framework, it is applied to a case study from the literature consisting of a hypothetical irrigation system including seven crops (wheat, gram, mustard, berseem, sugarcane, cotton and paddy). The model was run with a monthly time step for one year. Crop production functions presenting the relationship between the amount of irrigation water applied and crop yield are used to calculate net return (used as the objective function driving the optimization process) for different irrigation water allocations. Different maximum water availabilities are considered with three scenarios representing the water losses in the main water courses and field channels (25%, 10% and 0%, respectively). The MAX-MIN Ant Systems (MMAS), an improved form of ACOA, is used to find the optimal solution(s). These solutions are compared with the solutions obtained using linear programming (LP) in the literature. The results of this comparison show that the economic benefits of the whole system achieved using the ACOA model are slightly better than those obtained using LP, while the amount of water used in the solution obtained using the ACOA model is slightly less. In general, the results in this paper demonstrate the effectiveness of the proposed optimisation framework for water allocation in irrigated agriculture.

Keywords: *Optimisation, Irrigation, Scheduling, Ant Colony Optimisation*

Quantifying in-stream and overland flow generation mechanisms using fully integrated flow models

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Abstract: Surface water and groundwater systems exhibit important feedbacks that influence the hydrologic response, water quality and ecology of catchments. Understanding surface and subsurface flow processes and the interactions at their interface requires that the physics driving the interactions/processes are well understood. Fully integrated surface-subsurface flow models (i.e. simultaneously solving the surface and subsurface flow equations) play an important role in helping to understand and quantify flow generation processes and surface-subsurface interactions. However, current analysis and interpretation of outputs from fully integrated surface-subsurface flow models does not exploit the wealth of spatiotemporal information provided. A key shortcoming of current methods is the inability to use model outputs to interpret both in-stream and overland flow generation mechanisms and surface water-groundwater interactions with respect to the streamflow hydrograph.

A previously developed Hydraulic Mixing-Cell (HMC) method which allows for quantifying in-stream and overland flow generation mechanisms within fully integrated models of surface-subsurface flow was implemented within the HydroGeoSphere model code. In-stream flow generation mechanisms are defined here as all mechanisms occurring at the stream interface, e.g. rain falling directly on the stream, groundwater discharging directly to the stream and overland flow into the stream at the stream's edges. Overland flow generation mechanisms refer to those occurring adjacent to the stream, e.g. rainfall on the hillslope causing overland flow (which could be from infiltration excess or saturation excess) and groundwater discharging to the hillslope. By spatially identifying where different flow generation mechanisms take place and temporally tracking the consequent surface flows, it is possible to relate these mechanisms to the streamflow hydrograph.

The HMC method utilises the fluid mass balance at each node or cell within a surface-subsurface flow model and applies a mixing-rule in order to track the flow generation mechanisms. The HMC method was used in a series of test cases to quantify the contributions to total streamflow of groundwater discharge to the stream and hillslope, and direct rainfall to the stream and hillslope. The test cases comprise a model of a riparian wetland and catchment. This method was used to investigate wetland and catchment processes in the test cases through separation of streamflow hydrographs and spatiotemporal analysis of flow generation processes. The analysis elucidated the dynamics of overland and in-stream flow generation processes as simulated by the model. This allows for new ways of analysing and interpreting flows within catchments using fully integrated surface-subsurface flow models.

Keywords: *Streamflow generation; Integrated surface-subsurface flow modelling; Surface water-groundwater interaction;*

EXTENDED ABSTRACT ONLY

Local model emulation for Markov Chain Monte Carlo simulation of a river management model

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Abstract: Markov Chain Monte Carlo simulation for Bayesian inference of parameter and prediction distributions of river management models is often hampered by the computational resources required. In this study we propose a model emulation technique that locally reproduces the response surface of the river management model, based on an efficient, extensive sampling of the original model parameter space. This exploration of model parameters space still requires a considerable number of original model evaluations, but it allows to dramatically decrease the simulation time of the Markov Chain Monte Carlo. This in turn provides opportunity to experiment with different priors or likelihood functions.

To test the methodology, we used an anonymised and idealised eWater Source model that reflects a flow regime and management representative for the Murray-Darling Basin in Australia. Considering uncertainty in inflows, rainfall and evaporation as well as in surface – groundwater interaction, a large number of simulations (100,000) were generated through Sobol' sampling of the parameter hyperspace. The response surface of the model is defined by the sum of squared residuals between the end of system flow and a synthetic observation timeseries with known observation error. The local model emulation is integrated in the proposal step of the Markov Chain Monte Carlo simulation, where the sum of squared residuals corresponding to the proposal is interpolated with a radial basis function based on the 50 parameter sets closest to the proposal parameter set. The likelihood of the proposal is calculated from the interpolated sum of squared residuals and incorporates a leave-one-out cross-validation estimate of the model emulation error.

The model emulation technique is used to explore different prior estimates of the parameters, number of simulations and likelihood functions, including likelihood functions that account for autocorrelation and heteroscedacity in the model results, with the goal to arrive at the most robust Bayesian inference of the posterior distribution of parameters and predictions.

Keywords: *River management model, model emulation, Bayesian inference, Markov Chain Monte Carlo*

An optimisation framework for scheduling environmental flow management alternatives in the South Australian River Murray

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Abstract: River development, such as dam construction and land conversions, has significantly altered many river-floodplain systems, such as the River Murray in Australia. This has changed the hydrological regime and in many cases resulted in the poor health of adjacent flora and fauna. In recent years, environmental flow management has been suggested to restore and preserve these systems and aims to mimic components of the natural flow regime (e.g. magnitude, duration, dry period), which are integral in maintaining and preserving biota within these systems. However, scheduling environmental flow management alternatives (EFMAs) (e.g. flow releases, wetland regulators) is difficult, since there are generally (i) many wetlands and floodplains containing a variety of species, (ii) multiple management alternatives (e.g. flow releases, wetland gate operation), (iii) system constraints (e.g. maximum flow rates), and (iv) limited water, that all need to be taken into account. To solve such a complex problem, an optimisation framework based on the systems approach is developed, which utilises a multi-objective ant colony optimisation algorithm in order to maximise the ecological response while minimising water allocation within system constraints. The framework is applied to a river reach in the South Australia River Murray (i.e. Locks 1-2), with the first stage of the framework involving the formulation of the problem, as shown in Figure 1. As part of the problem formulation stage the wetlands and floodplains within the river reach (i.e. 8 wetlands and the surrounding floodplains), ecological indicator (i.e. Murray Flow Assessment Tool (MFAT)), time period and interval over which the schedules is developed (i.e. 5 year and monthly time step), management alternatives (flow releases and operation of wetland regulators) and sub-options associated with the management alternatives (duration and magnitude) are identified. Next, the objective function and constraints are selected, which include the maximisation of ecological outcomes using MFAT and the minimisation of water allocation, while the maximum flow rate at the South Australian border considered is the only constraint. Once this has been defined, the schedule of EFMAs over the given time period is developed using a decision tree graph and the objective function calculated using a simple water balance model that is coupled with MFAT. This cycle of EFMA schedule development and assessment is completed many times using multi-objective ant colony optimisation (i.e. Pareto Ant Colony Optimisation Algorithm), until the termination criterion is met (i.e. the maximum number of iterations is reached) and a final set of EFMA schedules is determined and, in turn, the trade-off curve between environmental allocation and water allocation. To assess the effect of the system flow constraints at the South Australian border, and additional wetland regulators on this trade-off curve within the case study area, two studies are undertaken. The results indicate that system flow constraints should be relaxed in order to improve the ecological response with increases in water allocations, while increasing the number of regulators increases the ecological response using less water. The trade-offs developed demonstrate the utility of the framework and provide important insight to water managers.

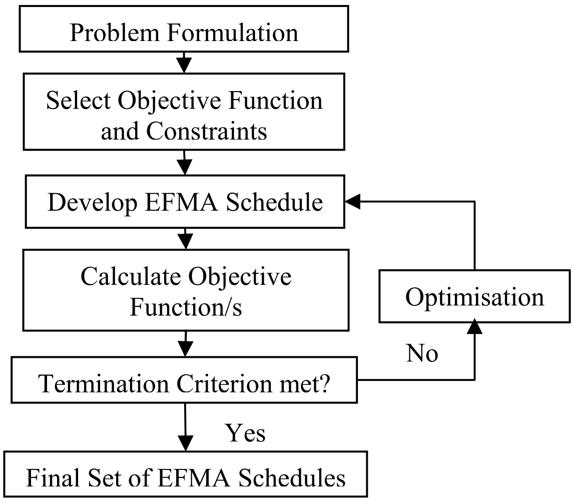

Figure 1: Steps in optimisation framework

Keywords: *Environmental flows, ant colony optimisation, River Murray*

Groundwater modeling for the Mekong Delta using iMOD

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Abstract: Groundwater (together with surface water) is essential to human live and socio-economic development in the Mekong Delta, Vietnam. It is extensively used by local people in the last decades especially for drinking water, agriculture and industry. Knowledge on the impacts on water systems by natural (e.g. climate change, sea level rise, and/or discharge variations from the Mekong River) as well as anthropogenic processes (e.g. increased population, agriculture, industry, land cover changes, and man-induced land subsidence) is still limited. In addition, (ground)water availability and variability as a function of time, is unclear. For these purposes, a supra-regional 3D groundwater flow model for the whole Mekong Delta using iMOD was developed. iMOD stands for Interactive MODeling and facilitates an easy-to-use modeling environment to engage stakeholders and stimulate participation in active groundwater management. Another difference compared to conventional modeling tools, is the generic geo-referenced data structure that may contain files with unequal resolutions and that can be used to generate sub-models at different scales and resolutions applying up- and downscaling concepts. This is done internally without creating sub-sets of the original model data. For modelers and stakeholders, this offers high performance, flexibility and transparency. We describe and demonstrate the flexibility and up- and downscaling abilities of iMOD by means of two local refinements for Ho Chi Minh City and Can Tho City.

Suppose the modeler needs to simulate groundwater flow for the total area covered by the data set, but the theoretical size of the model is far too big to fit in any CPU-memory. iMOD facilitates generating sub models for parts of the whole area of interest with a user-defined resolution depending on how large the available CPU-memory is and how long the modeler permits her/himself to wait for the model calculations to last. To generate a high resolution result for the whole model domain, a number of partly overlapping but adjacent sub models are invoked and the result of the non-overlapping parts of the models are assembled to generate the whole picture. The modeler should of course be cautious that the overlap is large enough to avoid edge effects, but this overlap is easily adjustable in iMOD. A big advantage of this approach is that running a number of small models instead of running one large model (if it would fit in memory, which it often will not) takes much less computation time; computation time (T) depends on the number of model cells (n) exponentially: $T = f(n^{1,5\text{-}2,0})$. iMOD also allows the utilization of parallel computing, but this is not obligatory. This approach allows the modeler to interactively generate models of any sub-domain within the area covered by the data set. Using this approach means that the modeling workflow is very flexible and not limited anymore by hardware when utilizing iMOD. This enables the IER, Can Tho University, DWRPIS and DWRM to proceed with building and improving (local) groundwater models in the Mekong Delta in any order, region after region or sub regions within larger regions with resolutions that fit the actual needs and still maintain consistency between the different sub models and resolutions.

Keywords: *iMOD, Mekong Delta, Vietnam, Groundwater Flow Modeling*

Generating synthetic rainfall using a disaggregation model

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Abstract: Synthetic rainfall data has a large number of uses. Specifically, the behaviour of a reservoir under most scenarios can be best understood when evaluated using a large number of synthetic inputs. These synthetic values are all equally probable to occur but many of them may not have appeared in the historical record. Stochastic weather generators produce these synthetic data that were statistically equal to historical records. Different approaches have been used to generate synthetic rainfall data, Markov Chains being the most frequently used method. One of the major drawbacks of the current models is that when synthetically generated daily rainfall is aggregated into monthly totals, it fails to demonstrate all statistical properties of monthly series. The same could be seen in seasonal and annual series as well. The above drawback is very significant in preserving the variance of the series. Since daily rainfall is the basis of higher order synthetic rainfall series, the preservation of all statistical properties should be a pre-requisite for its application in numerous hydrological, ecological and agricultural contexts.

A disaggregation rainfall model is presented in this paper that overcomes the drawbacks of earlier models, which could not produce coinciding statistical moments at all the time scales discussed above. In this model first a seasonal value is generated; followed by monthly values to tally with the seasonal total; and finally, daily values to tally with the monthly totals. Daily, monthly and seasonal rainfall have a skewed pattern, on $[0, \infty)$. A Gamma distribution is often used in the literature to generate rainfall amounts due to its similarity to the above pattern. However, some of the values generated using the Gamma distribution are high and unrealistic as it has no upper bound. Use of Beta distribution from the same family overcomes this limitation. Upper and lower limits are found using an Extreme Value distribution. The correlation structure of the rainfall differs with the place and time. When generating synthetic rainfall both the independent and correlated cases were considered. Spearman's correlation coefficient is used to find the correlation structure in the seasonal and monthly rainfall values while a Markov Chain is used to capture the underlying correlation in the daily rainfall. The Kolmogorov- Smirnov statistical test is used to check whether the simulated and observed values have statistically indistinguishable cumulative probability distributions. The model is demonstrated using data from two locations, Hume in New South Wales and Pooraka in South Australia.

Keywords: *rainfall, synthetic data generation, disaggregation, markov chain*

EXTENDED ABSTRACT ONLY

Atmospheric PM_{10} dispersion across South Australia

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Abstract: The aim of this study is to use a range of multivariate statistical methods to assess particulate matter less than 10 µm (PM_{10}) in O_3, NO_2 and SO_2 in the atmosphere that have been measured at daily and sub daily intervals at Elizabeth, Netley, Lefevre, Kensington and Northfield in South Australia over a 10 year period. We consider a windrose model to provide a graphical display of the frequency distribution and to detect the direction of PM_{10} over time. This study demonstrates the significant relationship between fine particulate materials and climate variables such as rainfall, temperature and wind speed. We found a significant (with 5% level) decreasing trend in the PM_{10} in O_3, NO_2 and SO_2 as wind speed increased and also as an increasing trend as rainfall decreased. Furthermore, the data are examined for trends or shifts under the mean using multivariate statistical quality control techniques. These techniques include regression, the Cumulative Sum (CUSUM) method, and the Holt-Winters model using deseasonalised time series. The CUSUM plots display steep slopes which correspond to periods of below average or above average PM_{10} concentrations rather than trends.

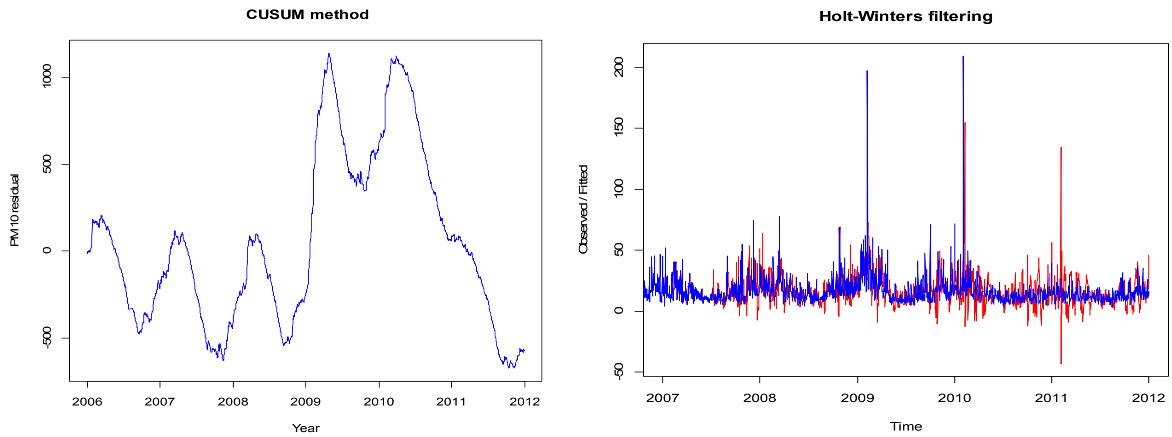

Figure 1: PM_{10} microgram loading at Elizabeth in SA a) estimated relative changes using CUSUM method b) predicted trend underlying the mean using the Holt-Winters method and red line represented one time step ahead prediction along with daily observed PM_{10} in blue line.

The results of the Holt-Winters analysis are consistent with those from the CUSUM method. The Holt-Winters method is a forecasting procedure that uses a smoothing parameter to identify the underlying level, trend and seasonal effects. Optimum smoothing parameters of 0.07 for O_3, 0.06 for NO_2 and 0.1 for SO_2 were selected using iteration procedures to predict PM_{10} concentrations one time step ahead in the atmosphere. The average value of trend over the entire period was found to be 0.027µg/m^3 for PM_{10}. Importantly, the statistical analyses used in this study can be regularly updated as more data become available.

Keywords: *PM_{10}, CUSUM method, Holt-Winters method, trend, windrose model*

The Interplay Between Rainfall and Vegetation

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Abstract:

There have been numerous studies detailing the deleterious effects of vegetation clearance on rainfall totals. Junkermann et al (2009) report on trends in rainfall in Western Australia. They state that

The western tip of the continent has experienced a reduction of precipitation by about 30% (from an average of 325 mm/a) since the 1970s, attributed to a change in the large scale surface pressure patterns of the southern ocean (Allan and Haylock, 1993; Smith et al., 2000) with a concurrent reduction in surface water fluxes (Bates et al., 2008).

We focus for the remaining investigation on South Australia, starting first with details of an investigation of rainfall trends in Cummins, on Eyre Peninsula, $34.26^0 S$, $135.73^0 E$. Despite some perceptions of increased rainfall in the region, I found a significant decrease in rainfall if you compared before and after 1975, roughly mirroring the Western Australian experience, even if not as extreme. Noteworthy is the fact that the land clearance in this area took place principally from the 1950s (Sindicic 2002), substantially later than in some other parts of South Australia.

The perception is that the extensive plantings on the Monarto plateau in the 1970s has led to increased rainfall on the plateau and close by. Unfortunately, the only official weather station on the plateau is at the Monarto Zoo, and has only been in operation sporadically. However there are official stations at Murray Bridge ($35.12^o S, 139.27^o E$) and Callington ($35.12^o S, 139.04^o E$) adjacent. Gallant et al (2007) studied rainfall trends from 1910-2005 in six regions of Australia. In their Southeast region, which includes this study area, their conclusion was that there has been *a significant decrease in annual total rainfall of 20 mm per decade since 1950 (that) stems mainly from decreases during autumn.* It is in this context that we present results from rainfall trend analysis for these stations and two further from the Monarto plateau It would appear that these two locations at the edge of the plateau are going against the trend, with increasing rainfall if one compares the period pre 1989 with that after, though not at a significant level. The year 1989 was chosen as this is one decade after the Monarto plantings. On the other hand, the trends at Mt Barker and Tailem Bend are consistent with the findings of Gallant et al (2007) of a diminishing rainfall in this area of the country, though not at as great a rate as they report.

Thus, there appears to be some evidence in Australia of the influence of introducing vegetation on rainfall as well as the more easily supported evidence of lowering of rainfall with land clearance. One must be guarded in this conclusion as there are always confounding factors, for instance changing weather patterns with climate change being one. But it does influence us to conduct more research into the topic.

Keywords: *Rainfall models, land-use, revegetation*

Quantify trends in rainfall extremes in South Australia

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Abstract: The aim of this study is to investigate whether there is evidence of trends in rainfall extremes in data from selected South Australian (SA) weather stations that have six-minute rainfall records. This research is particularly important for Australia, given the water sensitivity of its flora and fauna to even slight climatic changes and variability. We carry out such an analysis by aggregating six-minute time steps rainfall up to 24 hours in six-minute time steps. We consider the factors: time, seasonal indicators and weather station locations to provide a graphical display of extreme intensities over time. We have quantified the variation in rainfall extremes at daily and sub-daily intervals at the same rainfall station in the same year using a self-organising map. This study suggests that monthly rainfall extreme significantly decreasing over the period 1977-2005. The strength of this evidence is assessed using a multivariate control chart, based on Hotelling's T-squared test and a multivariate cumulative sum (CUSUM) method. An alternative method has been applied to verifying the fitted model using the Ljung-Box test. The goodness of fit test took account of the variation in peaks for predicting rainfall extremes. The results indicate that there is no substantial statistical evidence of any trends in rainfall extremes in the selected SA weather stations. The 6 minute and 24 hour peak extreme rainfalls at Adelaide Airport are shown in Figure 1. The estimated variation is 0.35 mm for 6 minutes and 0.69mm for 24 hours calculated over a 12 year period.

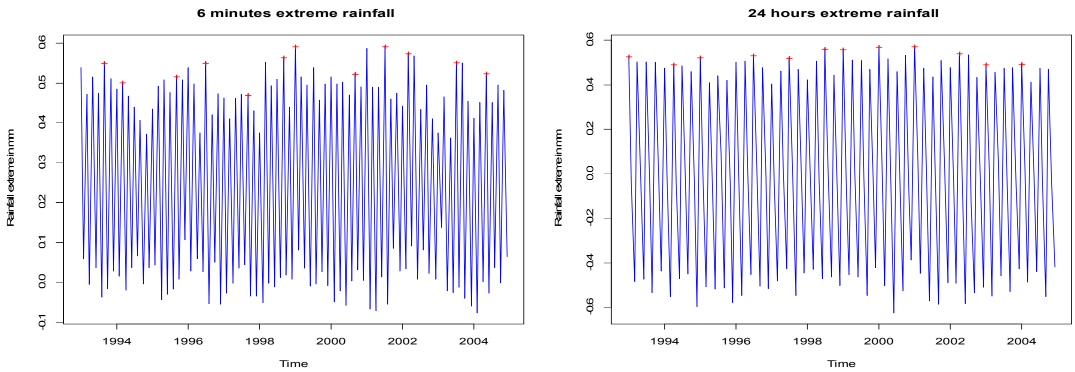

Figure 1: Extreme rainfall at Adelaide Airport based on a) 6 minute peak (left) and b) 24 hour peak (right).

Critical values were determined by simulation because an assumption of normality is not a satisfactory approximation. As an alternative approach, a multivariate Bayesian change point analysis is applied to investigate the possibility of sudden change rather than a smooth trend. Importantly the statistical analyses can be regularly updated as more data become available.

Keywords: *Bayesian analysis, Extreme rainfall, Holt-Winters method, Ljung-Box test, Multivariate CUSUM, Hotelling's T, self-organising map*

Autumn precipitation trends over southern Australia and other Southern Hemisphere midlatitude regions as simulated by CMIP5 models

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Abstract: In recent decades, Southern Hemisphere (SH) midlatitude regions such as southern Africa, southern Chile and southern Australia have experienced a reduction in austral autumn (March–May) precipitation. While the cause of this precipitation decline is not well understood, it has been suggested that the expanding tropics and a poleward shift in extratropical weather systems might play a role in driving these trends. This study focuses on the ability of Coupled Model Intercomparison Project phase 5 models to simulate these trends, their relationship with extratropical and subtropical processes, and implications for future precipitation changes.

The majority of models simulate positive trends in the Southern Annular Mode (SAM; 27/34 models) and subtropical dry-zone expansion (29/34 models). However, the trend in the multi-model ensemble (MME) SAM index is only about half the strength of that observed, although 11 models simulate the SAM trend reasonably well. The large range in subtropical dry-zone expansion rates estimated from two reanalyses makes assessment of the models' performance difficult.

The MME is unable to capture the spatial pattern of observed autumn precipitation trends across midlatitude regions, particularly over southeastern Australia, the region of strongest observed precipitation reduction. However, in regions located further poleward, such as southern Chile, the MME simulates observed precipitation declines. Although weaker than observed, the MME suggests that the SAM and subtropical dry-zone trends may have contributed to the observed drying in southern Chile. Conversely, the MME suggests changes in these circulation features should have driven an increase in precipitation across much of southern Australia, in contrast to observations.

Nevertheless, regions where autumn precipitation trends are simulated more accurately tend to correspond to regions strongly influenced by the SAM, with precipitation trends found to be congruent with SAM trends in both the models and the observations. The strength of modelled precipitation trends in these regions is also found to be proportional to the strength of the modelled SAM trends and a strong coherence between the strength of SAM trends and subtropical dry-zone expansion in the models is noted.

The MME shows a strong consensus in twenty-first century declines in autumn precipitation across southern Chile in both the medium-low and high anthropogenic forcing scenarios, and across southern Africa in the high forcing scenario, but little and inconsistent changes across southern Australia. Projecting a strong positive SAM trend and continued subtropical dry-zone expansion, the models converge on large SAM and dry-zone expansion-induced precipitation declines across the more southern midlatitudes. In these regions, the strength of future precipitation trends is proportional to the strength of modelled trends in these phenomena, suggesting that unabated greenhouse gas-induced climate change will have a large impact on autumn precipitation.

Future trends during autumn in southern Australia are less clear and the autumn SAM trend and subtropical dry-zone expansion cannot account for, and in fact may have offset other climate variability modes that have contributed to the observed precipitation decline. To assist in reducing the uncertainty in future precipitation projections, further work investigating the limited ability of climate models in simulating observed historical trends in precipitation over southern Australia is required.

Keywords: *Precipitation, Southern Annular Mode, subtropical dry-zone expansion, CMIP5*

Simulation of extreme rainfall from CMIP5 in the Onkaparinga catchment using a generalized linear model

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Abstract: Due to the changes in global climate, the intensity, frequency and magnitude of heavy rainfall events are changing and this has been documented in many recent studies. Increasing trends in extreme rainfall directly affects infrastructure, agriculture as well as public and ecosystem health. So, projection of changes in extreme rainfall events is useful for policy making associated with climate change adaptation. General Circulation Models (GCMs) are the most important tool for climate change impact studies. But due to their coarse spatial resolution and their inability to capture local rainfall processes, GCMs cannot be used directly in hydrological impact studies. To bridge this gap downscaling has often been applied to transform GCM information to a finer resolution. There are broadly two types downscaling, namely dynamic and statistical methods. The latter is inexpensive and readily implementable compared to dynamic downscaling. Among several statistical downscaling techniques, generalized linear model (GLM) based downscaling techniques incorporate the spatial-temporal structure of rainfall. Because of this, GLMs have been used in several recent studies. However, application of this technique for downscaling of extreme rainfall events is relatively new.

In this study, a GLM based multi-site downscaling technique has been applied using the GLIMCLIM software package for downscaling extreme rainfall in the Onkaparinga catchment at nine rainfall stations. A GLM was fitted to the observed rainfall conditioned to several large scale atmospheric and circulation variables from NCEP reanalysis data for the calibration period 1991 to 2005. This relation was used to simulate the daily rainfall for the validation period (1981 to 1990) using NCEP reanalysis and CSIRO MK3.6 historical data and for the future period 2041 to 2060 using RCP4.5 and RCP8.5 scenarios of CSIRO MK3.6. These daily rainfall series were used to estimate extreme rainfall indices such as consecutive dry days (CDD), rainfall events greater than 10mm/day (R10) and annual maximum daily (AM) rainfall. As far our we are aware, this is the first attempt where a GLM technique has been applied for downscaling extreme rainfall events using large scale data from CMIP5 GCMs at least for the Australian climate. The study reveals that the model performed reasonably well in reproducing the CDD and AM rainfall whereas it underestimated the R10 statistics in most of the months of the year when driven by NCEP reanalysis data. Although the R10 was underestimated, the trend and variability were simulated well. Performance of the model deteriorates when driven by CSIRO MK3.6 historical data. Simulation differences between NCEP reanalysis and MK3.6 can be attributed by the bias in the large scale atmospheric and circulation variables.

AM daily rainfall was reasonably downscaled for NCEP reanalysis data over the period 1981 to 2005, whereas it was overestimated most of the time at all rainfall stations in the simulation driven by MK3.6. AM rainfall magnitudes for different Average Recurrence Intervals (ARIs) when fitted to Log Pearson Type III distribution were significantly larger for the period 2041 to 2060 under both RCP4.5 and RCP8.5 scenarios of MK3.6 compared to the observed data over the period 1981 to 2005. But the reduced accuracy in the simulation run using MK3.6 data may be due to bias in the large scale atmospheric and circulation variables relative to NCEP reanalysis. The study concludes that the GLM can be used to downscale extreme rainfall events. Also non-stationarity in relation to local rainfall and large scale climate variables is considered as a source of uncertainty in climate change impact studies. Most importantly adequate bias correction in the GCM data is essential before any projection is made.

Keywords: *Generalized linear model, general circulation model, CMIP5, Extreme rainfall events*

Suitability of a coupled hydrodynamic water quality model to predict changes in water quality from altered meteorological boundary conditions

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Abstract: The application of downscaled climate scenarios can be used to inform management decisions on investment in water treatment infrastructure or alternative water sources. Appropriate models of the system components potentially impacted by climate change such as catchments, rivers, lakes and reservoirs are required. The sensitivity of the coupled hydrodynamic water quality model ELCOM-CAEDYM to climate drivers was investigated to determine its suitability for evaluating climate change impacts and to evaluate the most important climatic drivers.

A case study application of the model to Happy Valley Reservoir was used in the investigation (Romero et al. 2005). The hydrodynamic model was validated against field measurements without calibration. The ecological model was set up using values derived from literature sources and measurements made at other reservoirs. Manual calibration of some parameters was performed, however, performance metrics were not provided by Romero et al. (2005).

A series of simulations were run with altered boundary condition inputs for the reservoir. Air and inflowing water temperature (TEMP), wind speed (WIND) and reservoir inflow and outflow (FLOW) were altered to investigate the sensitivity of these key drivers over relevant domains. The simulated water quality variables responded in the broadly expected manner to the altered boundary conditions; sensitivity of the simulated cyanobacteria population to increases in temperature was similar to published values. This study demonstrated that ELCOM-CAEDYM is sensitive to climate drivers and suitable for use in climate impact studies. It further highlighted the important factors in determining phytoplankton growth and that any changes in inflowing water quality will be of major importance to the dynamics of raw water quality.

Keywords: *Water quality; Sensitivity analysis; ELCOM-CAEDYM*

Realism of climate modes in CMIP5 models: the implication for climate projections

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Abstract: Recent studies have shown that the impact of the Indian Ocean Dipole (IOD) on southern Australia occurs via equivalent-barotropic Rossby wavetrains triggered by convective heating in the tropical Indian Ocean during austral spring (September-November, SON). Furthermore, the El Niño-Southern Oscillation (ENSO) influence on southern Australian climate is exerted through the same pathway during austral spring. It is also noted that positive phase (positive IOD (pIOD) and El Niño) events have a much larger impact, associated with their respective skewness. These phenomena play a significant role in the region's rainfall reduction in recent decades and it is essential that climate models used for future projections simulate these features. An assessment of how well climate models simulate the IOD, its rainfall teleconnection to southern Australia, along with ENSO, is undertaken using coupled models that have partaken in the Coupled Model Intercomparison Project Phase 5 (CMIP5). The majority of CMIP5 models generate a larger variance of sea surface temperature (SST) in the Sumatra-Java upwelling region and an IOD amplitude that is far greater than is observed. We demonstrate that climate models do indeed simulate a greater climatic impact on Australia for pIOD events than for negative IOD (nIOD) events but this asymmetric impact is distorted by an exaggerated influence of La Niña emanating from the Pacific. The distortion results from biases in the Pacific in two respects.

First, the tropical and extratropical response to La Niña is situated unrealistically too far westward and, thus, too close to Australia. This results from the tropical convection anomalies and the extratropical Pacific-South America (PSA) pattern being situated too far westward during La Niña events, impinging on eastern Australia, leading to an overly strong impact on southeast Australia that shows up through the nIOD–La Niña coherence. Second, the majority of models simulate a positive SST skewness in the eastern Pacific that is too weak, over-estimating the impact of La Niña, relative to that of El Niño. The overly large impacts from La Niña again manifest through its coherence with nIOD. The lack of an orographic effect due to low model resolution may help generate a pan-Australia rainfall effect exacerbating the tropical bias. As such, the impact of the positive asymmetry in the IOD only becomes apparent when the impact of ENSO is removed. This model bias needs to be taken into account when analysing projections of regional Australian climate change. Future projections of SON rainfall changes over IOD-influenced regions are intrinsically linked to the IOD amplitude and its rainfall teleconnection in the model present-day climate. The diversity of the simulated IOD amplitudes in CMIP5 (and CMIP3) models, which tend to be overly large, results in a wide range of future modelled SON rainfall trends over IOD-influenced regions. Underpinning the overly large amplitude of the IOD are modelled Bjerknes-like feedbacks that are too strong. With a stronger Bjerknes-like feedback strength, the magnitude of the eastern Indian Ocean response to climate change perturbations is greater, leading to a greater rainfall reduction in IOD-influenced regions, where a positive IOD leads to reduced rainfallOur results highlight the importance of realistically simulating the present-day IOD properties and suggest that caution should be exercised in interpreting climate projections in the IOD-affected regions.

Keywords: *IOD, ENSO, rainfall teleconnections, tropical climate variability, climate change*

Hydrological evaluation of statistical downscaling in the Onkaparinga Catchment

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Abstract: The evaluation of historical simulations from downscaled climate models in replicating historical patterns of rainfall and potential evapotranspiration (PET) is an important precursor to applying such models for future climate projections. The transformation from rainfall and PET to runoff is often complex and highly non-linear, so that it is beneficial to evaluate not only the statistics of rainfall and PET directly, but also to evaluate the performance of runoff timeseries generated using the downscaled data. This provides an indication of how possible biases or errors in the rainfall and PET can cascade through the hydrological modeling system.

In this study, the performance of the Non-homogenous Hidden Markov Model (NHMM) is evaluated by comparing runoff simulated using the NHMM-derived data with the runoff simulated using the observed rainfall and PET. The evaluation was based on the NCEP/NCAR reanalysis, as well as historical runs from five Coupled Model Intercomparison Project Phase 3 (CMIP3) GCMs: GFDL-2.0, GFDL-2.1, MIROC3.2(medres), CSIRO-MK3.5 and ECHAM/MPI. The conceptual hydrological model GR4J was used for this analysis, and was applied to three sub-catchments in the Onkaparinga region of South Australia: Scotts Creek, Echunga Creek and Houlgrave Weir.

The findings were that there were some biases in the simulations using the NHMM data (see Fig 1 for Scotts Creek catchment), although in most cases the streamflow obtained from the observed rainfall and PET were within the range of the NHMM simulations. The most notable biases occurred for the high (99 percentile) flows, which were underestimated for the reanalysis and most GCM historical runs. A detailed analysis suggested that this bias is not only due to biases in the high quantiles of the rainfall data, but also due to the multi-day dependence of rainfall (i.e. the probability of having multiple wet days in a row). These biases also led to biases in annual flow volumes, because of the importance of a small number of wet days to the total flow volume.

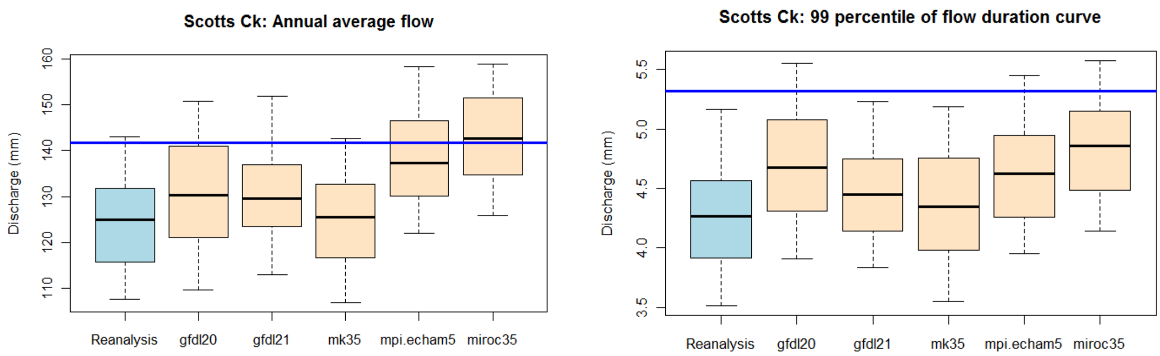

Figure 1: Box and whisker plots of average annual flow and the 99 percentile of the flow duration curve, for Scotts Creek catchment. The observed value is given by the blue horizontal line. The box describes the 25, 50 and 75 percentile values obtained from the 100 NHMM simulations, whereas the whiskers indicate the minimum and maximum values.

Keywords: *Climate change, hydrological modelling, statistical downscaling, GR4J, NHMM.*

Diagnosing hydrological non-stationarity in Scotts Creek catchment

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Abstract: The development of hydrological models that can provide credible catchment runoff projections under a future climate constitutes one of the most challenging aspects of hydrological modeling. The challenge becomes particularly acute when extrapolating outside the domain over which the model has been calibrated, which becomes necessary as we look further into the future or consider higher greenhouse gas emission scenarios.

To address this challenge, we present a strategy for diagnosing and interpreting hydrological non-stationarity that centers on simulating hydrological model parameters as a function of one or more time-varying covariates. This approach is motivated by the understanding that non-stationary parameters can indicate that one or more important processes are not adequately represented by the model, so that a covariate-based approach will assist with the diagnosis and interpretation of such non-stationarity. The strategy consists of the following four elements:

(i) *Quantification of systematic biases in the observational data*. The role of possible biases and systematic changes in the measurement of hydrological data needs to be understood, and where possible eliminated before proceeding with the hydrological modelling.

(ii) *Modelling one or more parameters as a function of time-varying covariates*. These covariates should represent different functional forms of possible non-stationarity. In our case we selected a sinusoidal function with a period of one year, a linear trend, and the previous 365-day aggregate rainfall and potential evapotranspiration.

(iii) *Comparison of alternative model structures*. The presence of non-stationarity indicates that key processes are not adequately represented by the model, and this step therefore seeks to identify missing or poorly represented processes. Where possible, the hydrological model is modified to account for those processes, and step (ii) is then repeated to determine whether the parameter non-stationarity is reduced.

(iv) *Model selection and evaluation.* Steps (ii) and (iii) both involve identifying a set of candidate models that represent competing hypotheses of system behaviour. The final step is to evaluate the empirical support for each of the candidate models, and an information-theoretic approach based on the Akaike Information Criterion as well as several other diagnostic tools are used to aid with this step.

Scotts Creek catchment, a small catchment located in South Australia, is used as a case study to illustrate the strategy, with GR4J selected as the hydrological model. The case study revealed that the maximum capacity of the production store (parameter x_1) exhibited significant non-stationarity, particularly at seasonal timescales. Several modifications to GR4J were then made, including adding an additional parameter to the equation that controls the portion of net rainfall entering the production store, and these modifications improved model performance. Using the dry decade from 2000-2009 as an independent period for model evaluation, it was found incorporation of non-stationary parameters and other model improvements reduced the bias in annual average flow from 18% to between 3 and 7%.

Keywords: *GR4J, hydrological modelling, non-stationarity, model selection, hydrological model diagnostics, AIC*

Reconciling surface and groundwater models in a climate change context

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Abstract: To understand the possible impacts of changes in rainfall and potential evapotranspiration (PET) in a river catchment in which surface water and groundwater systems are connected, the dynamic interaction that exists between changes in surface runoff, groundwater recharge, and groundwater levels must be represented appropriately. While such a system can be modelled using fully coupled groundwater-surface water flow models, it is more common for separate specialised models to be developed independently by different teams for different purposes. The assumptions, parameters and outputs of the models are not compared.

This paper develops a methodology for comparing specialist hydrological models commonly used in Australia to simulate catchment processes. Three models were developed, initially independently, of the Cox Creek sub-catchment in the Mount Lofty Ranges of South Australia: a LEACHM model of groundwater recharge, a SOURCE model of surface water runoff, and a MODFLOW model of groundwater flow. The models are reconciled by using multiple outputs of the LEACHM model as inputs to the MODFLOW model, and calibrating the MODFLOW model to SOURCE outputs. Reconciliation of the inputs and outputs of the three models with each other should improve the rigour in each model's simulation of catchment processes. The reconciled models will be run with stochastically-generated input data sets of rainfall and PET, representing a variety of possible future climate scenarios generated by one of the CMIP5 group of global climate models. Reconciled outputs of the three models are expected to reveal some of the complexities in the inter-related responses of groundwater and surface water flow systems to multi-decadal timescale changes in rainfall patterns.

Keywords: *Groundwater modelling, Surface water modelling, Recharge modeling, climate change*

Weekly comparative evaluations of some high resolution water stress variables at the Riggs Creek OzFlux tower site

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Abstract: From a hydroclimatic perspective, the standardized values of the main variables of the hydrological cycle (precipitation, streamflow (runoff and underground flow), soil moisture and evapotranspiration) can be used as proxies for drought, normal and wet conditions. Such variables may also be defined as water stress variables (WSVs). In past studies in Australia (Risbey 2011), WSVs that have been under consideration to evaluate the water stress status are generally based on rainfall indicators, such as the standardized precipitation index (McKee et al. 1995). However, recent research has identified drawbacks of this approach at the water management level, showing that for evaluating water stress, it is necessary to consider all main WSVs simultaneously.

One of the main impediments when assessing and monitoring WSVs is the availability of reliable data. Over the recent decades, advancement in monitoring and modelling technologies have opened possibilities to water resources experts to access a large number of high resolution data products. These products provide information on the surface processes, both in terms of the water and vegetation dynamics, as well as for the surface-to-atmosphere interactions. Amongst the available in-situ data sources throughout Australia, flux tower sites provide the most comprehensive and complete point data sets. In the present study, daily time series of precipitation, streamflow, soil moisture and evapotranspiration observed at the Riggs Creek OzFlux tower site are used in a proof-of-concept study. The reason for selecting this site lies in having full access to data, little to no data gaps, and a relatively homogeneous pattern of landuse (dryland agriculture) within the tower's footprint. The Riggs Creek site is located within the Goulburn-Broken catchment, south-east of Shepparton, in Victoria (36° 39'S, 145° 34'E). The data used here spans from November 2010, the beginning of its operational period, to December 2012.

The methodology presented in this paper is a step-wise process (Fig. 1): first, all variables are standardized using an equiprobability transformation, presented by Panofsky and Brier (1958). Then, statistical parameters such as, maximum, minimum, kurtosis and skewness of the data are calculated. Next, the best probability distribution functions (*pdf*) for the data sets are chosen via two statistical indicators, the Kolmogorov–Smirnov and Chi-squared, as the goodness of fit tests. After this step, the probabilistic amounts of normal and extreme events of WSVs based on their cumulative distribution functions (*cdf*) are extracted. Moreover, for each variable, the severities of extreme dry and wet events are calculated by considering magnitude and duration of events. Finally, to specify the correlation and relationships between WSVs, an analysis based on the agglomerative hierarchical clustering (AHC) is applied (Murtagh and Contreras 2012). In the present case, the linkage criterion of "*Ward*" and similarity function of "*Pearson Coefficient*" are used in the mentioned AHC. Further, to determine the accuracy and efficiency of the final clusters, a "*Cophenetic Coefficient*" (0<CC<1) is calculated. The higher the value of CC shows the better the accuracy of the final clustering. The results of this research can be used in helping managers to have further reliable information over weather and climate behaviours of different areas to apply in water resources management and planning. Here, initial results will be discussed and compared to the skills of traditional methods.

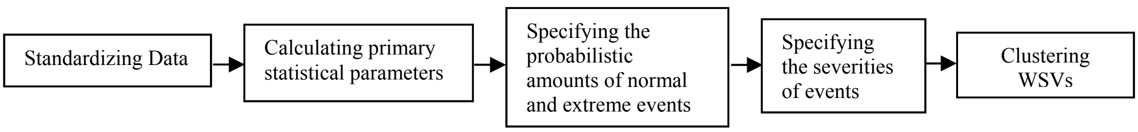

Figure 1. The step-wise process of used methodology in current study

Keywords: *water stress variables, Riggs Creek OzFlux tower, statistical methods*

3D visualisation of groundwater systems

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Abstract: For sustainable management of Australia's groundwater systems to occur, a good understanding of how these systems work is essential, not only for the hydrogeologists investigating these resources, but also for the decision makers (managers, politicians) and those who use and depend on the resources (irrigators, industry, rural populace). This understanding is hard to achieve, given that groundwater occurs below the ground surface and is hidden from view.

Visualisation of groundwater systems in 3D is valuable tool to enhance the understanding for all stakeholders. This visualization is typically applied to layered sedimentary aquifers where the extent, thickness and configuration of sedimentary units can be used to help define groundwater flow systems, delineate discrete layers for input into groundwater flow models and calculate volumes of groundwater in storage within various aquifer layers. Visualisations can also provide validation of data whereby interpretation or data errors can easily be distinguished.

Examples included in the presentation include creating aquifer surfaces in the Murray and Otway Basins in South Australia using over 5000 well logs covering an area of about 73,000 km^2. These surfaces will be used to construct a groundwater flow model in the Southeast of SA. Another example is the calculation of the saturated thickness of the unconfined limestone aquifer on Eyre Peninsula in order to determine the volume of groundwater stored in the aquifer for water allocation purposes.
Another form of useful 3D visualization is the creation of time series animations of various types of groundwater data to examine short to medium term trends. This applies to potentiometric surface elevations and also groundwater extraction volumes from licensed wells. This process assists in assessing the adequacy of groundwater monitoring networks and also to provide some data validation.

Comprehensive and accurate data are desirable to create meaningful visualizations.

Keywords: *3D visualization, sedimentary aquifers, groundwater models, groundwater extraction*

An overview of Australian Water Resources Assessment reporting

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Abstract: The Bureau of Meteorology, through the Water Act 2007, has been given responsibility for conducting regular assessments of Australia's water resources. This followed water reforms in Australia that were initiated in the 1990's with a focus on delivering efficient and sustainable use of water resources based on a thorough understanding of the Australian hydrological system and its spatio-temporal variability.

The 2012 Assessment is the second of the Bureau's regular series of such reports that combines observed data, outputs from a continental water balance model and advanced analytics to provide the status and conditions of use of the Australian water resource on a national scale as well as across 13 regions covering the whole of Australia. Much of the observed data used in the Assessments are provided to the Bureau under the Water Regulations 2008. The report supports informed decision making and dynamic management by policy-makers, water managers and planners of water in both the rural and urban sectors

This paper provides an overview of the 2012 Assessment. It presents highlights of the water situation in Australia including precipitation, evapotranspiration, landscape water yield, soil moisture, surface water storages and urban water use during the 2011–12 year (July–June) and compares them to the long-term record.

The paper also introduces strategies being implemented to stimulate the uptake of the assessment reports by stakeholders. The outcomes of a user response survey are presented in this regard.

Keywords: *Landscape water balance, water resource assessment, stakeholder engagement*

Urban CALculator Model (UrbanCALM): Consistent and efficient urban water balance reporting tool for simple and complex systems

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Abstract: Urban water managers face a number of complex challenges in the planning, development and delivery of robust and secure water services (water supply, wastewater and stormwater management). These include the need to supply and service growing populations and urban areas and manage the impacts of climatic variability.

Increasing access to accurate and timely information on intake, usage and discharge by urban water systems can assist the efficient management of the water resources available for urban purposes. The Bureau of Meteorology (under the *Water Act* 2007) has responded to this information need by developing reporting products and tools to meet its legislated role in providing an annual National Water Account and a regular (bi-annual) Australian Water Resource Assessment Report. Both products provide insights into urban water systems.

The Urban CALculator Model (UrbanCALM developed by the Bureau provides a consistent and efficient water balancing tool for both simple and complex systems. UrbanCALM builds on the structured data capture and innovative framework of UrbanSAT (Urban System Analysis Tool) developed by the Bureau. It facilitates consistent analysis, automates outputs and provides insights into urban systems for their integration into Bureau reporting products. A case study shows the application of UrbanCALM to the complex Melbourne region water system in 2011-2012. The flexibility of the UrbanCALM framework has been tested through its capability to represent water systems of other major Australian population centres, with varying level of complexity in: water intake, transfers and supplies for use; and wastewater collection, treatment, discharge and recycling.

The case study demonstrated that UrbanCALM is a simple, user-friendly tool which enables stepwise, systematic evaluation of the Melbourne region water system. It includes multiple checks to detect gaps and anomalies in the usage of urban water data. These features help accurate and consistent interpretation of flows and evaluation of water balances, and improve the transparency of flow through each subcomponent of the urban water system: water supply system, wastewater system and recycled water system.

UrbanCALM is adaptable to systems with varying level of complexity as demonstrated by its application to major Australian cities. It provides a framework for analyzing and summarizing urban water balance in a consistent manner at: (1) water utility and regional scales (through appropriate aggregation of the utility based water systems) in Melbourne, Sydney and Canberra; (2) regional scale in Adelaide and Perth; and (3) regional scale in South East Queensland (SEQ) complex, multi-utility water system. In addition to the common urban flows, UrbanCALM appropriately accommodates system specific flows within the consistent water balance framework. Examples are: flows back to storage from the water supply system (Canberra, Perth), recycled water on-site within process re-circulation use (Melbourne, Sydney, Canberra); treated wastewater discharge to sewer for further treatment (Canberra); recycled water advanced treatment (SEQ); and multiple imports for water supplies (Adelaide).

In conclusion, UrbanCALM facilitates consistent and efficient water balance evaluations and strengthens the Bureau's ability to produce high quality reporting products. This study reveals the strong potential for its broad application across all Australian urban centers as well as internationally.

Keywords: *Urban Calculator Model (UrbanCALM), Urban water balance tool, Consistent urban systems analysis*

WAFARi 2.0: Upgrade of an operational modelling system for the seasonal streamflow forecast service of the Bureau of Meteorology, Australia

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Abstract: The Bureau of Meteorology (the Bureau) launched a new Seasonal Streamflow Forecasting (SSF) service using a statistical modelling approach in December 2010. In addition, the Bureau developed a new modelling system to ensure the timely and reliable delivery of the service's three monthly streamflow forecasts (updated every month) called WAFARi (Water Availability Forecasts of Australian Rivers).

WAFARi is written primarily in Python with the user interface consisting of simple Python methods accessed interactively through the IPython interpreter. WAFARi is equipped with a variety of tools to support the entire SSF workflow from end to end. This includes diverse tasks such as data ingestion from a database, model simulation, and web publication on the Bureau's operational web servers. Using WAFARi hydrologists can store and manage data in self-descriptive files and generate publication-quality graphics products. All these tools are available through the scripting environment of Python, either in an interactive command shell or using script files. The Bureau pushed WAFARi version 1.0 into production for driving the public forecasts from December 2010.

Recently, the Bureau upgraded WAFARi to version 2.0 in order to support a dynamic modelling approach as well as the statistical method. The dynamic modelling approach generates streamflow forecasts by running rainfall–runoff models calibrated using a novel approach and driven by downscaled rainfall forecasts from a global circulation model. The challenge was to maintain the system's standard for a manageable and highly usable architecture, even with the introduction of new modelling components. To facilitate the support of both statistical and dynamic approaches, WAFARi has been refactored over two years into a Model–View–Controller (MVC) architecture. This has enabled greater re-use of code between the approaches and facilitated the standardisation of method interfaces and data structures. WAFARi's system architechture and file formats were redesigned to support both modelling approaches with existing program code and the same user interface.

As the forecasting output from both the statistical and dynamic approach is an ensemble of possible streamflow outcomes, all the existing products could be reused to visualise the ensemble forecast. To enable switching between the models used for dynamic forecasting, they were isolated as kernels and interfaced with WAFARi using adapters. These adapters wrap existing FORTRAN code that implements the rainfall–runoff models to provide a common interface regardless of the model used.

Insights from this development can be useful in guiding other projects building operational systems that support multiple modelling methods.

Keywords: *Streamflow, forecast, model, system, Bureau of Meteorology*

Rainfall-runoff modelling with downscaled rainfall forecasts for a seasonal streamflow forecast service

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Abstract: The Australian Bureau of Meteorology (the Bureau) launched a seasonal streamflow forecast (SSF) service in 2010 to provide updated water resource information. Since then, the SSF forecasts are provided every month using a statistical modelling method called Bayesian Joint Probability (BJP).

In parallel, the Bureau has produced experimental forecasts using a dynamic modelling approach. Rather than using statistical relationships between streamflow and climate indices, we have: 1. downscaled regional rainfall forecasts from the Predictive Ocean Atmosphere Model for Australia (POAMA) to the catchment scale, 2. calibrated the GR4J rainfall-runoff model with a heteroscedastic residual error model using the Bayesian Total Error Analysis (BATEA), 3. produced ensemble streamflow forecasts and 4. applied an error correction method. The dynamic modelling approach aims to simulate the nonlinear rainfall-runoff processes which occur in catchments by explicitly accounting for temporal variation in soil moisture.

Compared with the statistical approach, the dynamic approach results in more accurate and/or precise forecasts at several locations across different seasons. However, overall forecast performance of the dynamic approach remains lower than that of the statistical approach. The dynamic approach tends to overestimate streamflow volumes in catchments from drier regions, which results in poor reliability. Without any form of post-processing, the approach tends to generate emphatic forecasts with narrow uncertainty bands. Errors in rainfall forecasts downscaled from POAMA are the major source of the streamflow forecast uncertainty in many locations.

Once forecast quality from the dynamic approach improves, we plan to merge the probabilistic forecasts from both approaches into a single forecast. We expect that merging will help extend the SSF service into diverse climate regions.

In this paper, we introduce details of the dynamic modelling approach, evaluate and compare the modelling outcome, and explain future development of the SSF service.

Keywords: *Streamflow, forecast, model, season, water, Bureau of Meteorology*

Defining a water quality vocabulary using QUDT and ChEBI

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Abstract: Vocabularies of observed properties and associated units of measure are fundamental to understanding of groundwater, surface water and marine water quality observations. The ability to support annotation of observation values from the disparate data sources with appropriate and accurate metadata is crucial to achieving interoperability; that is, precisely describing metadata relating to the magnitude of a physical quantity denoted by a unit of measure in a machine readable format.

Previous projects have developed stand-alone water quality vocabularies, which provide limited support for cross-system comparisons or data fusion. We propose that relationships between the water quality concepts, the associated chemical entities and appropriate units of measure be represented formally using ontologies. As part of the development of a new water quality ontology for groundwater and marine domains, we have reused and aligned our definitions with existing ontologies. We use the 'Quantities, Units, Dimensions, Data Types' (QUDT) ontology to provide a consistent model of measurable quantities and units, and the Chemical Entities of Biological Interest (ChEBI) ontology for observations relating to chemical concentrations. In this paper we demonstrate reuse of these ontologies for describing observation values in the water quality domain. We show how QUDT can be used to define additional quantity kinds and units of measure relevant for the domain and how use of ChEBI enriches the water quality ontology, while maintaining separate ontology governance.

Keywords: *ontologies, water quality, QUDT, ChEBI, vocabularies*

Modelled Groundwater Recharge and Discharge: Effects of Climatic Conditions

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Abstract: The Bureau of Meteorology (the Bureau) has published an annual National Water Account since 2010. The National Water Account reports information on different water stores and flows including the annual flows to and from groundwater storage and changes in groundwater storage. Diffuse groundwater recharge, which is the fraction of rainfall that drains below the root zone to the watertable, is a key inflow to the groundwater store in high rainfall areas. In areas with shallow watertable, diffuse discharge, an upward flow of groundwater by evapotranspiration (ET) to the atmosphere, can occur. The Bureau uses the numerical soil water model WAVES to provide consistent estimates of potential groundwater recharge and discharge on an annual scale, throughout Australia. WAVES was widely used by the CSIRO in the Sustainable Yields studies. The Bureau has built on this methodology by adding the effects of annual variation in the depth to watertable (dtw). The WAVES version used at the Bureau uses the standard rooting depths, soil types, climate variables, and additionally, 4 classes of dtw: <=2 m, 2.1-3 m, 3.1-3.9 m and >=4 m (free drainage conditions).

The sedimentary areas within the Melbourne reporting region (MSA-3,000km^2) and the Northern Victorian Riverine Plains (RP-22,630km^2) in Murray Darling Basin are used in this work. The WAVES model was run on annual basis (financial year) from 2007-12 for MSA and 2007-11 for RP, using an average depth to watertable for each year. A dtw surface is interpolated using the 9" Digital Elevation Model and kriging with external drift (KED), a methodology developed in collaboration with Melbourne University.

Between 1997 and 2009 inclusive, south-eastern Australia including MSA and RP experienced the most persistent rainfall deficit since the start of the 20th century the so-called "Millennium Drought'. In 2010/11, the world experienced one of the strongest La Niña episodes on record. The episode produced widespread flooding across the study areas. This study therefore focuses on analysing the impacts of the described climatic conditions on the net groundwater recharge and discharge in the two regions.

Table 1 Modelled net groundwater recharge (R) and discharge (D) in GL/year and mean rainfall in mm/year

Region	2007-08			2008-09			2009-10			2010-11			2011-12		
	R	D	rain	R	D	rain	R	D	rain	R	D	rain	R	D	rain
MSA	346	15	560	227	17	480	336	11	710	916	4	1000	585	9	820
RP	337	320	350	127	229	360	410	108	520	1956	200	870	-	-	-
Climate	millennium drought									wet					

Table 1 shows that as expected, there is a large increase in the net recharge when going from dry to wet climatic conditions in both regions, however, a more complex situation for net groundwater discharge is noted in general. For the RP net discharge decreases from 2007-2010 followed by an increase in the net discharge in the first year after rain, while in the MSA, net discharge was lowest in 2010-11 and only appears to rise in the second year after the drought (2011-12). Within the study regions, the extent of the shallow watertable increased from dry to wet weather conditions (data not shown), however, this did not appear to increase net discharge. In both MSA and RP, some areas of shallow watertable did not result in net discharge – the dominant types of soil within these areas are hydrosol, vertosol, and sodosol and the vegetation types are shallow rooted annuals and perennials. The described local soil and vegetation in these areas are possibly not conducive to net groundwater discharge conditions.

Overall, the results show that the weather conditions directly affected the modeled net groundwater recharge. In the case of groundwater discharge, wet weather increases areas of shallow watertable, however, this may or may not result in increased discharge. This application of the WAVES model allowed representation of shallow watertable conditions.

Keywords: *groundwater, diffuse, recharge, discharge, WAVES, model*

Modelling of return periods of extreme rainfall events in Brisbane, Australia

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Abstract: Recent extreme rainfall events in Brisbane, Queensland caused damages to society and natural resources through the destruction of infrastructure. Hence, an attempt was made to perform the modelling of return periods of extreme rainfall events for that city. The Gumbel distribution function was applied to 25 years (1988 to 2012) daily rainfall data and a modelling equation was developed to determine the return periods for probable extreme rainfall events. To regionalize the modelling results, some of the steps of CRC-FORGE (Focused Rainfall Growth Estimation) technique were adopted for Brisbane region.

Daily rainfall data of six rain gauge stations -- 040767, 040245, 040383, 040212, 040224 and 040326 of Brisbane were collected from Australian Bureau of Meteorology in June 2013. The Gumbel distribution function was applied to the data set and found significant spatial variation of return periods. The following steps were applied to regionalize the findings: i) selection of a focal point for CRC-FORGE analysis, ii) delineation of a sub-region by considering the focal point station and other two rain gauge stations closest to it; statistical modelling was performed to the pool data of this sub-region and iii) another sub-region was formed by doubling the total number of stations and repeated the above steps until homogeneous findings were available.

The analysis showed that annual daily maximum rainfall of 300 mm would have return periods of 21 and 119 years for Brisbane RPA Hospital (040767) and Ashgrove Bowls Club (040326) respectively. For regionalized result of Brisbane, the return period is 75 years for 300 mm annual daily maximum rainfall (Figure 1). Equation 1 shows the developed formula for the estimation of return periods of extreme rainfall events for that region. The outcomes of this study can be used for upgrading the capacities of existing drainage systems in Brisbane, Queensland.

$$N = \left[1 - \exp\left[-\exp\left\{-\left(\frac{x-103.67}{45.52}\right)\right\}\right]\right]^{-1} \qquad (1)$$

Where, x = annual daily maximum rainfall (mm/day),

N = return period (year).

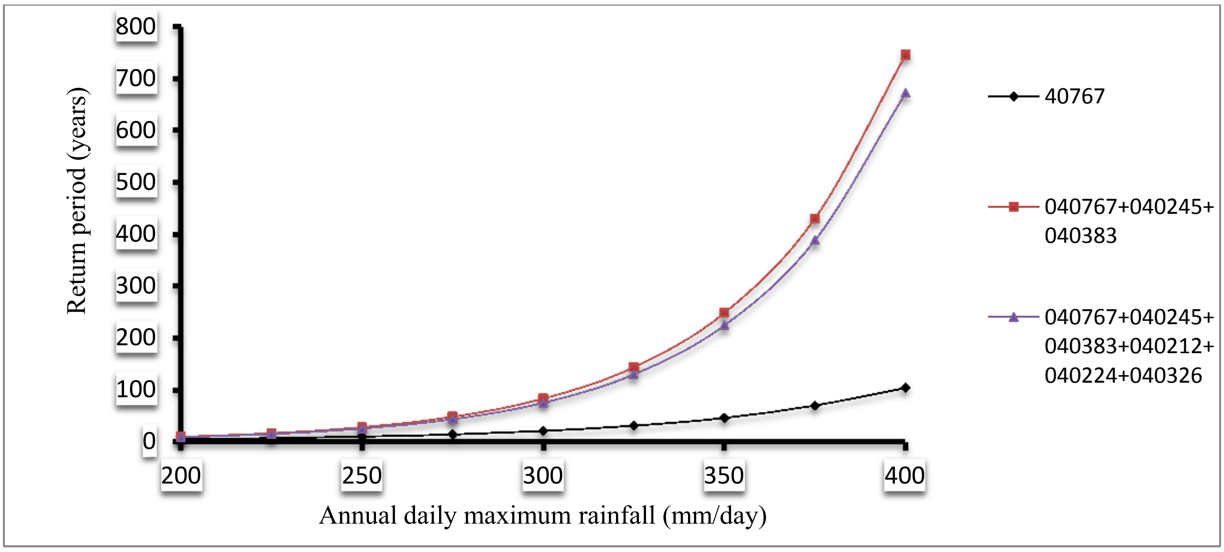

Figure 1. Return periods of annual daily maximum rainfall in Brisbane region.

Keywords: *Extreme rainfall events, Return periods, Gumbel distribution function, CRC-FORGE technique.*

Prediction of Tropical Cyclone Activity with Coarse Resolution Global Climate Models

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Abstract: The generation of monthly to seasonal forecasts of tropical cyclone (TC) activity using physically based coupled ocean-atmosphere general circulation models (GCMs) has become feasible. GCMs not only simulate many of the large-scale processes that determine local favourability to cyclogenesis, but have also been shown to generate TC-like vortices and to reproduce key aspects of ENSO related variability in the spatial distribution of TCs.

In this study, seasonal TC predictions from two coupled ocean-atmosphere GCM based seasonal prediction systems are examined: the Japan Meteorological Agency/Meteorological Research Institute Coupled GCM (JMA/MRI-CGCM) and the Australian Bureau of Meteorology's (BoM) Predictive Ocean-Atmosphere Model for Australia (POAMA-M24). To evaluate the influence of model composition and tracking technique on seasonal TC predictions, two different TC tracking methods are applied to both models' hindcasts over the period 1981 to 2010. In the more traditional TC detection scheme, TCs are identified where sea level pressure is a minimum and the magnitude of 850-hPa relative vorticity exceeds a certain threshold. A second TC detection scheme, developed at BoM for use with low-resolution climate models, uses the Okubo-Weiss-Zeta Parameter (OWZP), to identify regions with low-deformation flow and large amplitude vorticity. The schemes use warm-core criteria including moisture and wind shear thresholds and vertical structure criteria to eliminate cold-cored systems and ensure that only tropical disturbances in favourable environments are identified as TCs.

Both models and tracking schemes reproduce the inter-annual variations in the spatial pattern of TC genesis between El Niño and La Niña years. ENSO related variability which is reproduced includes 1) the northward shift of genesis location in El Niño years in the south-western Pacific, 2) increased TC genesis on the northern coast of Western Australia and in the eastern Indian ocean in La Niña years, and 3) increased genesis in El Niño years to the north of Madagascar. These results suggest that GCM-based forecasts of TC genesis will have skill for years in which ENSO has a strong influence on the pattern of cyclogenesis.

Relative vorticity at 850 hPa and the 850 to 200 hPa wind shear are important local environmental parameters affecting TC formation, and so the spatial pattern of predictability of these environmental fields is assessed over a hindcast period. Results indicate that model error remains a key limitation on potential forecast skill at seasonal timescales, with relatively low model skill at forecasting wind shear and vorticity north of Australia expected to limit the skill with which interannual variability in TC tracks can be forecast in this region.

Keywords: *Seasonal forecasting, Tropical Cyclones, Global Climate Models*

Assessing the impacts of changes in the Hadley Circulation on stationary Rossby wave propagation

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Abstract: The Hadley Cell (HC) plays a key role in the climate system. Generally defined as the zonal mean meridional mass circulation in the atmosphere bounded roughly by 30ºS and 30ºN, with warmer air rising in the tropics and colder air sinking in the subtropics, this circulation transports momentum flux to the subtropics and heat from the tropics to the subtropics and to high latitudes through extra-tropical baroclinic eddies broadly organized into storm tracks and stationary Rossby waves. Through anomalous upper tropospheric divergence, modifications in the HC are connected to changes in the generation of Rossby waves that propagate into the extra-tropics. Thus, tropical variability affects the extra-tropical atmospheric circulation.

Changes in the location, intensity or seasonality of major climatological features of the general circulation, such as the HC or Rossby waves, can have important implications for regional climates by modifying patterns of temperature and precipitation. Several studies have identified that, in the late 1970s and early 1980s, a major shift occurred in the structure of large-scale circulation in both hemispheres, including a weakening of HC. Thus, in this paper we investigate how the changes in the HC, which occurred in the mid-1970s, have affected the stationary Rossby wave energy propagation in the Southern Hemisphere (SH) extra-tropics. We have employed the CSIRO Mk-3L general circulation model in a simulation with observed sea surface temperatures (SSTs) and time evolving historical carbon dioxide concentrations. Our focus is on the performance of the model in simulating the climatology for the twenty year periods 1949-68 and 1975-94 and on comparisons with the corresponding observations.

We find that the model is quite skilful in reproducing the broad features of the important inter-decadal changes that occurred in the mid-1970s.

We have also analysed the Rossby Wave Source (RWS) and mid-latitude circulation responses at upper levels associated with tropical variability. The RWS forcing is found to be located directly over the high latitude downward branch of the local HC, which is associated with upper-level convergence zones. The vortex stretching term is the largest contribution to the total RWS and the term of absolute vorticity advection by the divergent flow is mainly associated with the anticyclonic anomaly sources in the subtropics.

The results also show that the weakening of the HC, which occurred in the period 1975-1994, leads to higher pressure developing over southern Australia, especially over southwestern Australia, contributing to rainfall reductions in these regions.

Keywords: *Hadley circulation, climate modelling, stationary Rossby waves*

Trend analysis of rainfall losses using an event-based hydrological model in eastern NSW

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Abstract: Climate change is likely to impact on the magnitude and frequency of extreme flow events. Whilst flood data have traditionally been assumed to remain stationary, this may no longer be the case due to the effects of climate change. A number of studies have demonstrated trends and variability in annual maximum flood data across Australia. These findings have been supported by Australian climate change studies, which predict increases in extreme rainfalls, increasing evaporation and changes to soil moisture conditions. However, what it is more uncertain is the magnitude of these changes, the specific changes at a regional scale and the impact on catchment characteristics at the local scale and how this affects catchment response when a hydrologic model is to be developed.

This study investigates trends in loss parameters using an event-based rainfall-runoff model, for four catchments across eastern New South Wales. These catchments include the Orara River, Ourimbah Creek, Currambene Creek and Pambula River. The analysis explores three loss models, the initial loss-continuing loss (IL-CL) model, initial loss-proportional loss (IL-PL) model and Soil Water balance MODel (SWMOD). Trends were investigated for the loss parameters of all three loss models, including the initial loss (IL), continuing loss (CL), proportional loss (PL) and initial moisture (IM, from SWMOD). The relationship between trends in loss parameters and trends in the annual maximum flow series, antecedent precipitation index, annual runoff totals, annual rainfall totals, number of rainy days and inter-event duration are also examined.

In this study, four tests were adopted to test for trends, namely the Mann-Kendall, linear regression, CUSUM and cumulative deviation tests. Results from the tests of change and visual analyses show that for two of the four catchments there is strong evidence of an upward trend in the IL data, strong evidence of a downward trend in the IM data and strong evidence of a downward trend in the API data (28 days). The changes in the initial condition for rainfall-runoff modelling (IL and IM) correspond well to the trends in the API, as surrogate for the antecedent moisture content. Only one of the catchments saw a change in the continuing loss measures (CL and PL), however, this is also the only catchment that shows evidence of trends in the annual flood series.

Keywords: *Trend analysis, Mann-Kendall test, RORB, initial loss, continuing loss, floods.*

Trends in low flows in the Mount Lofty Ranges, South Australia

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Abstract: In this paper, we examine trends in various low-flow metrics in the Mount Lofty Ranges (MLR) in South Australia. There is evidence for changing large-scale circulation patterns having reduced rainfall amounts in southern Australia over the last few decades. Accompanying this has been a larger-than-expected reduction in annual runoff and low flow characteristics in moderate-relief, low- to medium-rainfall catchments. Possible reasons for this are reductions in surface-groundwater connectivity and increase in the number and volume of farm dams in recent years. Water resources in catchments in the Mount Lofty Ranges (MLR) are important for several reasons: supplying drinking water to Adelaide, supplying water for irrigation purposes, as well as providing water for many nationally significant wetlands. Some streams in the MLR region reduce to stationary ponds and pools during summer months. Reductions in low flows combined with extended dry season durations can result in a reduction in fresh water dilutions of these ponds and a subsequent reduction in water quality in water-dependent ecosystems.

We select nearly 30 unregulated streamflow records in the MLR region for analysis, which are daily gauged streamflow data provided by the South Australian Department of Environment, Water and Natural Resources (DEWNR). A subset of Kennard's 120 ecohydrological flow metrics are implemented, such as monthly and mean annual daily flow, variability and skewness of flow, baseflow index, low flow discharge and spell durations, and frequency of zero-flow days. Trends in annual values of these metrics are computed over the period of the data (which for most gauges is 1970-2012). Catchment flow regimes are classified into three categories: perennial, predictable ephemeral, and unpredictable ephemeral, based on a revised version of Kennard's catchment classification scheme. There is no discernible trend in low flows in the perennial catchments. However, the predictable ephemeral and unpredictable ephemeral catchments show a general trend for increased zero-flow days, decreased 90th percentile low flow discharge, and decreased and more variable baseflow index. We consider the possible causes of changes in low flows, examine differences between catchments in the study region, and discuss similarities to recent changes in other parts of Australia (e.g. far south-west Australia and south-eastern Australia).

Keywords: *Low flows, Mount Lofty Ranges, trend analysis*

Temperature and Rainfall Thresholds corresponding to water consumption in Greater Melbourne, Australia

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Abstract: Water demand modelling is a crucial issue in the current climate of water restrictions and water conservation in Melbourne, Australia. Average annual inflows into Melbourne's major reservoirs since 1913 dropped rapidly by almost 40% during the 1997-2009 (Millennium Drought). This led to the development of the Sustainable Water Strategy for Central Region by the Victorian Government. The Strategy identified wide range of actions to secure water supplies in Victoria´s Central Region for the next 50 years. The Strategy also sets a per capita consumption reduction target of 25% from 1990´s average use by 2015, increasing to 30% by 2020. Water conservation efforts and initiatives were and are being implemented with interest in quantifying the impact of water conservation programs on reducing water demand. However, evaluation of the effectiveness of these options requires considerable effort since each of these options has a distinguishing set of environmental, social and economic outcomes. There has been significant modelling made to date to incorporate the effects of water conservation programs, although these are still in the early stage of development.

Basic water demand models are based on the premise that total water use is made up of base use and seasonal use with base use characterised by the water use during winter. Previous models described base use to be mainly indoor use that is weather insensitive, however, a number of studies revealed that base use is weather dependent and water usage during winter months may include garden watering in some areas. In some cases, base use was modelled as representative of winter usage, based on the months of lowest usage in a year, but correlation of base use values with temperature and rainfall was not undertaken for residential water use. Even correlation of base use values with temperature and rainfall is still not undertaken for mixed water uses comprising of residential (indoor use), industrial, and commercial. In this context, there is still a need to investigate whether base use for water demand modeling is weather-insensitive or weather-sensitive. Hence, threshold of temperature and rainfall needs to be determined to investigate whether "base use" values which are mainly for indoor purposes are weather insensitive or whether "base use" values represent winter usage that may include gardening in other areas or cities i.e. weather sensitive and not mainly indoor use.

This paper determines the thresholds at which water consumption is independent of temperature and rainfall. In general, when surface air temperature increases, consumption of water increases and when rainfall increases, water consumption decreases. However, a threshold point is reached beyond which increase of temperature and rainfall values no longer result to increase or decrease in water consumption. In one word, beyond the threshold line water use is independent of temperature and rainfall. To fulfil the aim of this research, daily water consumption of Greater Melbourne from Melbourne Water and daily temperature and rainfall data recorded by Bureau of Meteorology, Australia from January 01, 1980 to December 31, 2009 are analysed.

From the analysis, temperature threshold is found as 15.53 °C for Greater Melbourne while rainfall threshold as 4.08 mm. It could be noted that at temperature higher than 15.53 °C, daily water use increases as the temperature increases but below this threshold, daily water use seemed to be independent of temperature and increases in water use at this level could be attributed to population increase or other factors. The identified temperature threshold accounts for 23 percentile of the daily maximum temperature recorded from January 1980 to December 2009 and usually occurred during the months of May–September. Daily water use increases as the rainfall decreases but above this threshold of 4.08 mm, any more rainfall would no longer contribute to daily water use reduction. This could be due to the resulting saturated soil moisture content or water use has already been driven to its base use level. The identified rainfall threshold accounts for 70 percentile of the daily rainfall recorded from January 1980 to December 2009.

***Keywords**: Temperature and rainfall thresholds, Water consumption, Water demand model*

Trends in Rainfall Patterns over the Tamarabarani Basin in Tamil Nadu, India

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Abstract: Rainfall is the key hydro-climatic variable that governs the regional hydrologic cycle and availability of water resources. Recent studies have analysed the changes in rainfall patterns at global as well as regional scales around the world. These studies have also suggested that any analysis of hydro-climatic variables should be performed at the local scale rather than at a large or global scale because the trends and their effects may be different from one location to the other.

The Tamarabarani River basin is one of the important basins in Southern Tamil Nadu with rich surface water resources. The basin is mainly agriculture based and people are engaged in the cultivation of various crops like paddy, cotton, sugarcane, groundnut, etc. The Tamarabarani River provides consistent irrigation to a large agricultural area within the basin. The Tamarabarani River and its tributaries have many dams, with reservoirs providing water for irrigation and power generation. The Papanasam and Manimuthar dams located on the western part of the basin are two of the major reservoirs that cater to the water requirements of the district. The basin receives a majority of its rainfall during the northeast monsoon, which is during the months of October, November and December (with November having the maximum rainfalls). Thus, step changes and trends in rainfall for these stations and during the monsoon months would especially be of interest to the farmers, irrigators and water resource managers in the basin.

Since no studies on hydro-climatic trend analysis were found specific to this basin, this study performs a spatiotemporal trend analysis on long-term rainfall records (1971-2000) at 14 measuring stations within the basin. The Mann–Kendall test was used to detect trends and the cumulative summation (CUSUM) technique was used to identify the trend beginning year for monthly rainfall data.

The results of the CUSUM test indicated that the two stations of Papanasam and Dam Camp located in the Western Ghats had a statistically significant step-up change during the late nineteen seventies and early eighties. The trend analysis results indicated that increasing trends were observed (for most of the months) at 3 stations, which are Dam Camp, Papanasam and Cheranmadevi. The Cheranmadevi station exhibited the maximum number of months (seven out of twelve) with statistically significant increasing trends. For Papanasam and Cheranmadevi, the month of November exhibited statistically significant increasing trends. This is encouraging from the irrigation point of view, since these stations are located on the forested western part of the basin, which forms the catchment area for the major reservoirs. Thus, there is an increase in potential for harvesting water from this part of the basin.

On the other hand, it is observed that five stations have exhibited predominantly decreasing trends for most of the months during the past three decades. These stations are Tirunelveli, Manimuthar, Nanguneri, Kovilpatti and Ayyikudi. Most of these stations are located in the central part of the river basin and these areas would need special attention as over exploitation of surface as well as ground water resources in these regions need to be restricted to conserve water for future use.

Keywords: *Trend analysis, Rainfall, Mann-Kendall test*

Future variations of rainfall events in the Japan region based on GCM outputs considering global warming

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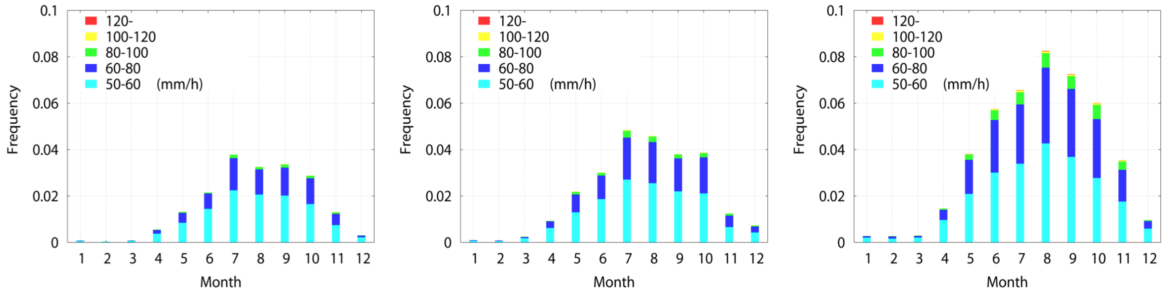
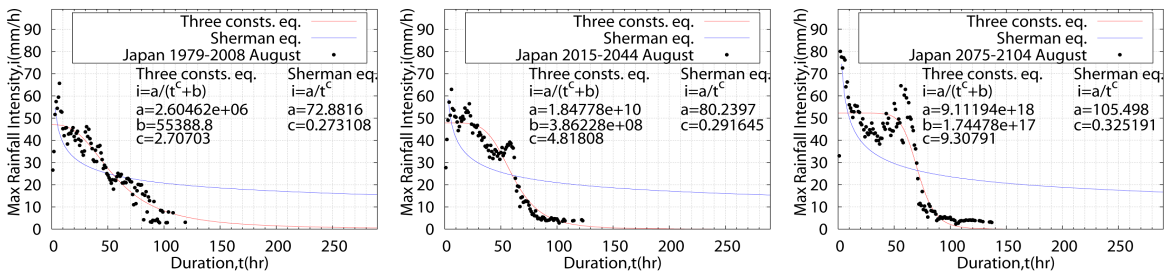
Abstract: There is growing concern about the significant increase of extreme meteorological events, e.g., torrential rains, heavy snows, and severe hurricanes, on a global scale in recent years. The current study conducted frequency and DAD (Depth-Area-Duration) analysis of torrential rains in order to examine future variations of rainfall events due to global warming, based on the MRI Atmospheric Global Climate Model 3.2S (MRI-GCM) outputs with a high horizontal resolution of 20 km, calculated under the present condition (1979-2008), near-future condition (2015-2044), and future condition (2075-2104) by the KAKUSHIN Program of the Ministry of Education, Culture, Sports, Science, and Technology (MEXT) in Japan. The trend of sea surface temperature, projected according to the SRES A1B scenario in the IPCC AR4, was taken into account in the boundary condition of the model.

Results show that the occurrence frequency of torrential rains can markedly increase in some regions of Japan. As shown in Figure 1, the occurrence frequency in May to November is doubled between the present and future conditions in the whole Japan region. In the future condition, torrential rains with intensity greater than 100 mm/h are generated in the summer season, while the peak of the occurrence frequency shifts from July to August, compared with the present and near-future condition. DAD analysis was attempted to clarify whether and how the statistical relationship will change between maximum areal rainfall and the area and duration of each rainfall event. Results, indicated in Figure 2, showed that DAD relationship could significantly change in the future, and there could be a numerical increase in rainfall events which depart from the regression curve of DAD relationship due to a greater rainfall intensity or larger area of rainfall than most other events. Visual inspections of each event suggest that such extreme events could be attributed to Baiu front activated by the sufficient amount of water vapor and typhoons strengthened by the higher sea surface temperature due to global warming in the future.



(a) present (1979-2008) (b) near-future (2015-2044) (c) future (2075-2104)

Figure 1. Occurrence frequency of torrential rains with intensity greater than 50 mm/h in the Japan region.



(a) present (1979-2008) (b) near-future (2015-2044) (c) future (2075-2104)

Figure 2. Relationship between duration and intensity (DD relationship) of rainfall in the Japan region.

Keywords: *global warming, extreme meteorological events, DAD analysis, Global Climate Model (GCM)*

EXTENDED ABSTRACT ONLY

Spatial Rainfall Extremes: Are They Changing?

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Abstract: As the Clausius-Clapeyron (C-C) relationship predicts an approximately 7%/°C increase in the water vapor holding potential of the atmosphere, it could be expected that extreme rainfall would also scale at a similar rate. Recent studies have shown that extreme precipitation does scale with surface temperature, and broadly speaking, this rate agrees with that predicted by the C-C relationship. However, the findings of many statistical studies have shown that this scaling is more complex than the C-C relationship predicts. For example, where convective rainfall dominates, the scaling of extreme rainfall with temperature has been observed to be greater than that predicted by the C-C relationship, possibly due to greater rates of moisture convergence. In addition, at very high temperatures the direction of this scaling reverses with increases in temperature being associated with decreased extreme rainfall, possibly as a result of limitations on the relative humidity of the atmosphere. As extreme precipitation is largely associated with convection, and the scaling is above that predicted by the C-C relationship, it suggests that spatial and temporal rainfall patterns must also change and possibly scale with temperature. In this paper we examine whether any relationship between the spatial and temporal characteristics of extreme rainfall and temperature exist.

Using pluviograph and continuous temperature records across Australia, it was found that there exists a scaling relationship between spatial storm statistics and temperature. Approximately 100 stations were analysed. Independent rainfall events were matched to temperature and then spatial statistics were calculated using the rain records from neighbouring stations. Four key statistics of interest were chosen including the coefficient of variation, skewness, zero fraction, and, the change in the average precipitation with increasing distance. The scaling of all these statistics universally pointed to less uniform and more intense spatial storm characteristics with increased temperature. The more extreme the events considered the more pronounced this trend was.

A similar analysis was also performed for temporal rainfall trends. The scaling of extreme precipitation intensity with temperature was first calculated for various precipitation durations. The scalings obtained were then used to calculate a ratio for shorter to longer durations. This ratio was found to scale positively with temperature suggesting, throughout Australia, less uniform temporal rainfall patterns with increased temperature. However, when these results were compared to the coincident rainfall on an event by event basis, it was found that the scaling with temperature of the ratio of rainfall is actually region specific and may not respond as predicted by considering single durations independently. It was found that in the northern parts of Australia the temporal pattern of extreme rainfall events could become even less uniform than predicted.

In summary, this study investigated the scaling of extreme rainfall spatial and temporal statistics with temperature. Using a variety of spatial statistics it was shown that spatial patterns are likely to be less uniform with increased temperature leading to more extreme rainfall events. By calculating the ratio of extreme precipitation for a variety of durations, it was found that temporal patterns are also likely to become less uniform as temperatures increase. Unlike the spatial statistics however, these results seemed to be very region specific with a clear delineation at latitude 30°S.

These findings indicate that not only the precipitation intensities need to be accounted for when planning for a future climate but also changed spatial and temporal patterns. It may be that the changing nature of spatial and temporal patterns will result in greater flood impacts in a warming climate.

Keywords: *Climate, rainfall extremes, Clausius-Clapeyron scaling, spatial variability, temporal variability, temperature scaling*

Synoptic and dynamical analyses of ENSO extreme events over Australia

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Abstract: The El Niño Southern Oscillation (ENSO) plays a major role in the variability of Australia's climate. Periodic droughts and wet conditions follow the ENSO phases. Understanding ENSO and its effects on Australia is never more important than in the cases of extreme events such as severe droughts or flooding. In this paper, we examine changes in the basic climate state over Australia during the two extreme flooding periods of January 1974 and January 2011. 1973-1976 and 2010-2012 are considered the two most severe La Niña periods in terms of precipitation and flooding in Australia since 1900. The largest floods occurred during January 1974 and late December 2010 through January 2011, in both cases flooding the Queensland and New South Wales coastal areas, and in the latter case causing floods inland and south down to Victoria.

We employ complementary avenues of analysis, looking at both the synoptics and atmospheric dynamics of the southern hemisphere climate during these events. Synoptically, the circulation over Australia often changes significantly during La Niña phases. In strong La Niña periods, often there are persistent low pressure systems over Australia during flooding periods, replacing or displacing the typical high pressure system seen in neutral or El Niño conditions. In 2011, higher sea surface temperatures (SSTs) in the western Pacific, due to an unusually strong negative Indian Ocean Dipole (IOD), caused lower pressure over the Indian Ocean, Australia, Indonesia and the western Pacific and above-average amounts of atmospheric moisture. These low pressure systems persisted over Australia with the aid of blocking high pressure systems in the Tasman Sea and easterly onshore winds. These events, coupled with anomalously strong westerly winds bringing down the large amounts of monsoonal tropical moisture, led to intense flooding. January 1974 was a similar case, albeit with a weaker negative IOD and smaller SST anomalies. To distinguish the classes of disturbances active during these events, their initial growth, growth rates, and interactions, we examine the leading dynamical modes in both cases.

Dynamical modes associated with these flooding events are determined using a primitive equation instability model. We find that heavy rainfall is associated with increased growth rates of Kelvin waves, intraseasonal oscillations (ISO), monsoon disturbances, and associated blocking over the Tasman Sea, as well as some changes in the extratropical storm track modes. In particular, we find that the Kelvin wave grows explosively and is strongly convectively coupled in the Australian monsoonal region, enhancing convection over Australia. In addition, intraseasonal oscillations grow strongly in the Australian region and contribute to the convection and rainfall, at the same time. We find similar Kelvin waves and monsoonal modes in both events, although in 1974 both were slightly stronger than in 2011. Our dynamical analyses agree with the synoptic observations and provide a more complete description of the reasons for the severity of both events.

It appears necessary for several factors to be both present and timed accordingly for flooding impacts to be maximal. In both 1974 and 2011, active monsoonal modes and intraseasonal oscillations met unusually rapidly growing Kelvin waves. In 2011, a strongly negative IOD with high SSTs made more moisture available. Understanding the nature of these extreme events over Australia is a fundamental step in the pursuit of accurate predictions of future ENSO impacts, Australia's future climate and climate extremes, and water resources planning.

Keywords: *El Niño Southern Oscillation, extreme events, La Niña, monsoon, Kelvin wave*

Modelling sediment transport and deposition in shallow flow through grass buffer strips using machine learning

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Abstract: Grass strips are commonly used practices to reduce the amount of sediment delivery to aquatic systems. They change the hydrology and hydraulics of the flow, by decreasing the flow velocity and increasing the infiltration rate. In order to be able to predict the efficiency of grass strips in removing sediment it is necessary to consider the effects of major factors involved. Two statistical nonparametric machine learning models are developed using data from 34 different studies to predict the efficiency of grass strips on removing sediments in different conditions. Grass type, particle size distribution, slope, length of strip, and antecedent soil moisture, were the major factors on which the model was built. 204 observations were used in order to develop the model.

A 'decision tree' was developed in order to describe the effect of major factors on sediment retention in and around vegetated strips. The decision tree results showed that very high efficiencies in removing sediment are expected from low slope, dry and dense strips with lengths more than five meters. It also showed that the sediment trapping efficiency decreases dramatically as the inflow sediment contains higher ratios of fine particles. It was also concluded that trapping efficiency is significantly less in wet soils comparing to dry soils. Significant difference can be observed between the sediment trapping efficiency in different grass strip types. Dense strips can highly trap sediment even in high slopes and medium lengths, while sparse strips can trap sediment moderately. Grass strips of any kind cannot reduce the amount of sediment in the outflow significantly if the moisture content of the soil is high and the inflow sediment mostly consisted of very fine particles.

As decision trees are considered as weak learners, it was only used for interpreting the functionality of the involving processes, not to carry out predictions. An ensemble of decision trees was developed in order to predict the efficiency of grass strips on removing sediment in different conditions. The 'bootstrap aggregation' algorithm also called 'bagging' was used to build the ensemble learner. 90% of the data was used for training the model whilst 10 percent was kept for testing it. The model was assessed by comparing its results to independent data and the bias, coefficient of model efficiency, and the root mean square error of the model were 1.01, 0.51, and 14% respectively.

Results of the model show that even low lengths of stiff grass strips of very high density can trap inflow sediments significantly if soil is dry and slope is very low. As situation tends to extremes, including high slopes, low density strips, and high antecedent soil moisture, or a high ratio of fine particles in the inflow, very long strips are needed in order to trap sediments to a significant extent. Scenarios were defined and the statistical model results were used to clarify the gaps in the physical understandings of the processes in the available process-based models.

Keywords: *Grass strip, Model, Machine learning, sediment, Decision tree*

Sensitivity analysis for a proposed sewer overflow screening device

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Abstract: Sewer overflows to receiving water bodies cause serious concerns for the environment, aesthetics and public health. To overcome these problems a self-cleansing, low maintenance, high capture efficiency and less expensive device was developed and tested at Swinburne University of Technology, Melbourne. There are a number of different screening systems used in sewer overflow screening devices. Most of the screener has the common drawbacks in the available commercial devices include inadequate screening capacity, external power needs and high cost. To overcome such drawbacks a new overflow sewer device, known as the 'Comb Separator' was proposed. The device has no moving parts, a robust stop/start operation, an effective self-cleansing mechanism, low maintenance and operation costs and no external power requirements.

The proposed experimental device in the present research is sewer gross pollutant trapping device, which consists of a rectangular tank and a sharp crested weir. In front of the weir a series of vertical, parallel combs to separate entrained sewer solids from the overflow as shown in Figure 1. The studied device was tested with a series of sewer solid materials including condoms, tampons, cigarette butts, cotton buds, bottle caps, wrap papers etc. Larger sewer particles (greater than 10mm diameter) can be captured relatively easily with capture efficiency more than 90%. This capture efficiency was tested with different input varying condition; however the output capture efficiency has insignificant variation from varying input parameters. However, significant variation observed from varying input parameters for smaller particles. Hence focus of this work is to parameter sensitivity on smaller sewer solid particles.

To improve output capture efficiency of these smaller particles, important input parameters like flow conditions, layers of combs and spacing of combs and weir opening were changed and tested with different trials. Average capture efficiency varies from 50% to 85%, however at times capture efficiency varied without varying input parameters, which triggered the need for a detail investigation of the parameter sensitivity. A total of forty (40) sets of experimental data were collected on eight different sets of experimental setup. Based on the experimental experience, four input parameters (flow volume, effective combs spacing, weir opening and number of comb layers) were identified influential on output sewer capture efficiency. Four different method of sensitivity testing were adopted these are Partial plots, Partial Correlation Coefficient (PCC), Sensitivity Index (SI) and Regression Analysis.

The partial plots suggest that inflow volume have a negative correlation with the output sewer capture efficiency. The 1st comb spacing has a positive correlation whereas the 2nd comb separator has a negative correlation. The weir opening has a positive correlation as wider weir area will reduce velocity and increase capture efficiency. Partial correlations suggest that weir opening is the most important parameter followed by 2nd comb spacing, inflow volume and 1st combs spacing. Sensitivity Index suggests all four parameters are varied 5% only for their sensitivity index. Regression analysis did not consider weir opening and comb layers as input parameters since these parameters failed to satisfy normal distribution assumption. Effect of 1st and 2nd comb spacing are combined in effective comb spacing (which shows bell shape trend of the input parameters) along with inflow volume as input parameters. Results shows inflow volume has significant influence output capture efficiency of the output parameter. Effective comb spacing combine the effect of comb does not provide any particular trend over capture efficiency although 1st comb has a positive correlation and 2nd comb spacing has a negative correlation with the capture efficiency.

Keywords: *Sewer Solids, Screening Device, Sensitivity Analysis, Trapping Efficiency*

Understanding functional efficiency of a sewer overflow screening device using combined CFD and analytical modeling

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Abstract: Recent developments of urban drainage are more concerned with water quality issues and aesthetic concern in receiving water bodies as sewer overflow can cause detrimental effects on the environment. The impacts of such uncontrolled sewer overflow include environmental, aesthetic, ecological and public health concerns. To overcome these problems different types of screening devices are used. Due to increasing public complaints, scientists and engineers are focusing on retention of the entrained sewer solids within the sewer overflow device.

There are a number of different screening systems used in sewer overflow locations. Some of the common drawbacks in the available commercial devices include inadequate screening capacity, external power needs and high cost. Research has been undertaken to develop a new sewer overflow screening device to overcome these existing limitations. Design criteria for the conceptual device needs to have a self-cleansing capacity to work efficiency in unstaffed remote locations, robust start-stop operations, device fail outlet for extreme events, no moving parts, no sophisticated electrical-mechanical signal, low maintenance and establishment cost etc.

Establishing an experimental setup involves significant cost and time; moreover it is important to maximize functional efficiency of the device as alteration of the device would be an expensive, troublesome and at times difficult to customize accordingly to existing urban drainage systems. State of art CFD modelling techniques can provide detail on the impacts of velocity, water level, shear stress, wave reflection etc.

A self-cleansing sewer overflow screening device with a sewer overflow chamber, a rectangular tank and a slotted ogee weir to capture the gross pollutants was investigated. To design an efficient sewer overflow screening device a 3D fluid dynamics model (CFD) was used. To understand dynamic flow properties such as velocity, water levels, wave refection and shear stress, two different inlet orientations; parallel and perpendicular to the weir direction were tested. The results are compared using simplified analytical model based on well-established physical laws.

Numerical results show that the flow is not uniform (across the width of the inclined surface) at the top of the inclined surface; however flow becomes uniform near the bottom. Uniform flow at the bottom of the inclined surface will help to remove pollutants adhered to the perforations. Due to varying water levels (high water level near the right side and low water near the left side), near the top of the weir surface, the self-cleansing property will not be as effective near the top region.

The CFD simulated shear stress is less than the analytical model as it is unable to consider flow undulations. Analysis of the shear stress along the flow path was performed to identify efficient self-cleansing screeners. CFD simulation showed that the shear stress increases significantly at the bottom of the inclined surface of the sewer screener device, which suggests that, the location of screen should be towards the bottom. Discussion of the comparison of CFD and analytical results will help to design an effective and efficient sewer overflow screening device.

Keywords: *Sewer Solids, Screening Device, CFD Modelling, Analytical model, screener location*

Selecting reference streamflow forecasts to demonstrate the performance of NWP-forced streamflow forecasts

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Abstract: We assess four different reference forecasts for the purpose of measuring the skill of streamflow forecasts generated from Numerical Weather Prediction (NWP) model rainfall forecasts. The reference forecasts we investigate are 1) streamflow climatology, 2) persistence, 3) a hydrological model forced by zero rainfall and 4) a hydrological model forced by an ensemble of resampled historical rainfall. We assess performance of reference forecasts to lead-times of 9 days. Reference forecasts should be simple to produce, but also must be reasonably accurate to establish a robust performance threshold. We show that because streamflows are strongly autocorrelated, streamflow climatology is a very low performance hurdle to clear for any NWP-forced streamflow forecasts, particularly at short lead-times (<2 days). Conversely, because the shape of hydrographs is broadly predictable, persistence forecasts generally perform very poorly at longer lead times (>1 day). Using a hydrological model substantially improves the accuracy of reference forecasts, with resampled–historical-rainfall forced forecasts outperforming zero-rainfall-forced forecasts, particularly at longer forecast lead times. We argue that streamflow climatology and simple persistence are not accurate enough to be used as reference forecasts. We recommend the use of reference forecasts generated by resampled historical rainfalls as a robust performance benchmark of NWP-forced streamflow forecasting systems. We demonstrate the use of resampled–historical-rainfall forced reference forecasts to assess the performance of a new Australian ensemble streamflow and flood forecasting system developed by CSIRO and the Bureau of Meteorology.

Keywords: *Streamflow forecast, reference forecast, forecast verification, numerical weather prediction*

EXTENDED ABSTRACT ONLY

Groundwater time-series modelling to quantify the impacts of land use change

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Abstract: In late 1980s and early 1990s there were many re-vegetation initiatives to address dryland salinity. These often involved reforestation or replacement of annual pasture with perennial pasture, such as Lucerne. The objective of such re-vegetation was to lower the watertable by reducing the groundwater recharge and increasing groundwater uptake. To monitor the groundwater level in response to the re-vegetation, groundwater observation bores were often installed and monitored at both the re-vegetated area and at a control area. In many regions the re-vegetation initiatives have continued for the last twenty years. However, climate variability makes quantifying the effectiveness of the re-vegetation difficult and existing methods, such as the HARTT time-series model (Ferdowsian *et al.* 2001), give highly inconsistent results (Peterson & Western 2011, Siriwardena *et al*. 2011).

To better account for the complicating factors of climate variability and an unknown impact from the re-vegetation, a nonlinear transfer function groundwater time-series model by Peterson and Western (2011) was applied to the Burkes Flat catchment, Victoria (~900 ha). Between 1983 and 1986, native trees were planted on the high recharge areas (about 4% of the catchment) and Lucerne and phalaris-based perennial pastures were established on the low to moderate recharge areas between the tree plantations and the discharge area. The discharge area was fenced off and planted to salt tolerant grasses, primarily tall wheat grass and puccinellia. By 1986, 90% of the catchment had been re-vegetated. Using only daily climate data and dates of the re-vegetation, the model was able to reproduce each of the observed hydrographs (Figure 1A) and did not require, as per the HARTT model, adoption of an unexplained temporal trend or an assumption of a stationary climate. At each bore a number of model structures for land use were investigated, including the removal of the land use module. Importantly, those bores at a re-vegetated site were best simulated when the land use module was included and the control bores were best simulated when the land use module was omitted. Hence, the land use impacts were concluded to be statistically significant. Using the most statistically significant model, the cumulative drawdown over time from the re-vegetation was quantified and decomposed into that due to reduced recharge and increased groundwater evapotranspiration (Figures 1B and 1C). By January 2013 the total drawdown from the re-vegetation was 5.9 metres; of which 0.7 metres was due to reduced recharge and 5.2 metres was due to increased groundwater evapotranspiration.

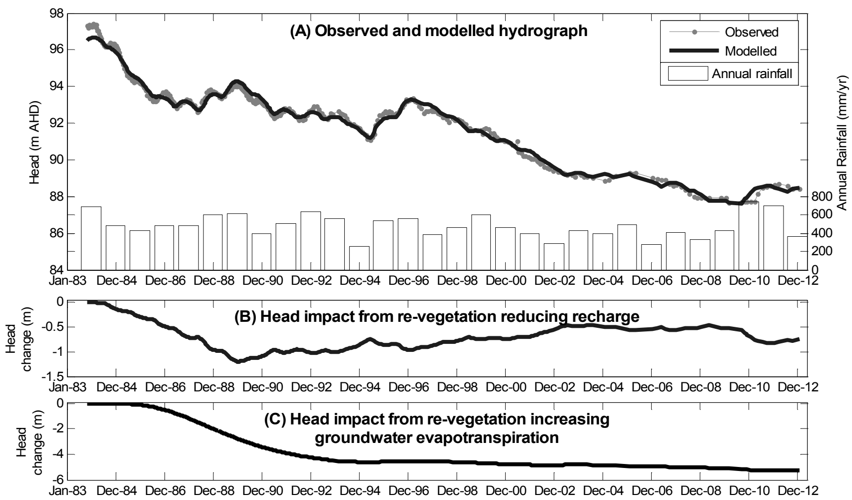

Figure 1: (A) observed and modelled hydrographs from bore 6412 and estimated impact of land use change on (B) recharge and (C) groundwater evapotranspiration at Burkes Flat, Vic., Australia.

Keywords: *Dryland salinity, groundwater hydrograph, time-series modelling, land use change*

Effects of climate and landuse activities on water quality in the Yarra River catchment

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Abstract: Since sediment and nutrient concentrations vary with landuses in different climatic conditions, it is critical in understanding the connection between different landuses activities and water quality, and developing appropriate management strategies for a catchment. The objective of this paper is to assess the effects of climate and landuse activities on nutrient and sediment loads at 5 selected water quality monitoring stations in the Yarra River catchment of Victoria, Australia for 1994-2008 periods. A data-based technique was applied to achieve the above objective using long-term in-stream water quality data and other readily available tools. The methodology addressed the issues of selecting water quality stations, catchment disaggregation, identification of major landuse types, analysis of pollutant concentrations and loads in different climatic conditions, and suitable data-based method (regression model LOADEST) to estimate pollutant loadings.

Climatic data were collected from the SILO climate database and the Bureau of Meteorology. Precipitation data from 16 stations and temperature data from 4 stations located in the Middle Yarra segment were collected for the period of 1980–2008. Daily streamflow and monthly water quality grab sample data of Total Suspended Solid (TSS), Total Nitrogen (TN) and Total Phosphorus (TP) were available for the 5 stations from Melbourne Water. ArcGIS 9.3 tool was used for catchment disaggregation and major landuse type identification using ASTER 30m global digital elevation model and landuse map (50m grid raster data collected from Australian Bureau of Agricultural and Resource Economics and Sciences). The water quality monitoring stations were selected based on data availability and dominant major landuse types (urban, agriculture and forest). The dominant landuse type in the tributary stations was either agriculture or urban where as in the main Yarra River stations; it was forest-agriculture mix type.

There was an abrupt drop in rainfall after 1996 known as millennium drought in the catchment, and the most extreme rainfall event occurs in that drought period. The study period was categorised into wet, dry and average years based on rainfall for water quality analysis purposes. Since the correlations between the concentrations of TSS, TN, TP, and streamflow (TSS: 0.57-0.72; TN: 0.50-0.57 and TP: 0.50-0.57 except station 5) were high and statistically significant ($p<0.01$), a regression method based model LOADEST was used to estimate constituent loads from the grab sample data. The LOADEST model is well documented, and is accepted as a valid means of calculating constituent load from a limited number of water quality data. The LOADEST model performed well in estimating TSS, TN and TP loads. Coefficients of determination (R^2) for the regression models in LOADEST were greater than 0.84, 0.94 and 0.88 for TSS, TN and TP respectively at all stations.

In general, TSS, TN and TP mean concentrations were higher in wet years than in the dry and average years, except at stations 2 and 3 where TN mean concentrations were higher in the average years. Also, TSS and TP mean concentrations were higher in the dry years than in the average years. This is due to the direct correlation of TSS and TP, and high runoff events. In addition, TSS, TN and TP mean concentrations were higher in the urban areas, and then in the agricultural areas. The four wet years (1995, 1996, 2000 and 2004) carried out on average 60% of TSS, 51% of TN and 53% of TP loadings in the monitoring stations. During the study period (1994-2008), the highest export rates of TSS, TN and TP were from urban areas, and the lowest export rates of TSS and TP were from forest areas, and TN from agricultural areas. Overall, water quality and constituent concentrations were influenced by rainfall events and landuse types.

Keywords: *Pollutant concentrations and loads, Climate and landuse activities, Water quality, LOADEST, Yarra River catchment*

Assessment of the indirect calibration of a rainfall-runoff model for ungauged catchments in Flanders

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Abstract: The practical application of rainfall-runoff (RR) models requires a proper assignment of the parameter values, also known as the process of parametrisation or calibration. Ideally, this calibration process should be fed by in situ measurements or remote sensing data. Practical considerations, however, implicate an alternative strategy. In a classic calibration framework, the parameter values are adjusted until the match between the modelled and observed output (e.g. discharge) is found to be acceptable. In practice the data to perform an ordinary direct calibration are not always available. This implies an indirect calibration strategy. In the past decade, the research concerning indirect calibration has gained attention in the hydrologic community through the Prediction in Ungauged Basins (PUB) initiative. This has also been recognized as very important in the Australian hydrologic community (Rahman et al., 2012). In scarcely gauged regions, discharge records may lack entirely for the catchment of interest, and may only be available at the outlet of a nearby catchment. Alternatively, data may be available for a specific period in the past, but these data may not overlap with the time period in which meteorological forcings are available.

This presentation focuses on the potential of discharge-based indirect calibration of the Probability Distributed Model (PDM), a lumped rainfall-runoff (RR) model. Six selected catchments in Flanders are examined. The concept of indirect calibration indicates that one has to estimate the calibration data because the catchment is ungauged. A first case in which indirect calibration is applied is that of spatial gauging divergence: Because no observed discharge records are available at the outlet of the ungauged catchment, the calibration is carried out based on a rescaled discharge time series of a very similar donor catchment. Both a calibration in the time domain and the frequency domain (a.k.a. spectral domain) are carried out. Furterhermore, the case of temporal gauging divergence is considered: Limited (e.g. historical or very recent) discharge records are available at the outlet of the ungauged catchment. Additionally, no time overlap exists between the forcing and discharge records. Therefore, only an indirect spectral calibration can be performed in this case. To conclude also the combination case of spatio-temporal gauging divergence is considered. In this last case only limited discharge records are available at the outlet of a donor catchment. Again the forcing and discharge records are not contemporaneous which only makes feasible an indirect spectral calibration. The modelled discharge time series are found to be acceptable in all three considered cases. In the case of spatial gauging divergence, indirect temporal calibration results in a slightly better model performance than indirect spectral calibration. Furthermore, indirect spectral calibration in the case of temporal gauging divergence leads to a better model performance than indirect spectral calibration in the case of spatial gauging divergence. Finally, the combination of spatial and temporal gauging divergence does not necessarily lead to a worse model performance compared to the separate cases of spatial and temporal gauging divergence.

Keywords: *Model calibration, Fourier analysis, spatial divergence, temporal divergence, ungauged basins*

Reliability Analysis for Rainwater Harvesting System in Peri-Urban Regions of Greater Sydney, Australia

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Abstract: Rainwater harvesting has become quite popular in Australia in recent years. In metropolitan areas, rainwater tanks are used to save mains water, but in peri-urban and rural areas, rainwater tanks are used as the principal water source to many households. In this case, the reliability of rainwater tank to meet given water demand is important. This study presents development of a rainwater tank model that can determine the tank size which can meet the most of the water demand in peri-urban areas. The model is a continuous simulation type, with daily time step.

The model is applied to 10 different locations in Greater Sydney and assesses the feasibility of 8 different rainwater tank sizes, 1 kL to 20 kL. Nine of these ten locations are situated in the peri-urban areas of Greater Sydney, which are Campbelltown, Hornsby, Penrith, Richmond, Castlereagh, Wallacia, West Pennant Hills, Moss Vale, and Cataract Dam. The other location (Parramatta) is situated in the approximate centre of the Greater Sydney, which is used for bench marking the water use in peri-urban and metropolitan Sydney regions. The daily rainfall data at each of the ten selected locations was obtained from the Australian Bureau of Metrology. The rainfall data lengths were in the range of 31 to 150 years, with an average of 73 years.

It has been found that for toilet and laundry use, a 7.5 kL tank can meet almost 100% of the demand, but to meet the irrigation demand, a much larger tank is needed. It has been shown that irrigation demand cannot be met 100% even with a tank size of 20 kL. The method presented in this paper can also be applied to other Australian states and countries to estimate water savings and reliabilities of rainwater harvesting system using daily rainfall data.

Keywords: *Rainwater tanks, rainwater harvesting system, peri-urban area, water sensitive urban design, reliability, water conservation*

Application of *eTank* for rainwater tank optimisation for Sydney metropolitan

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Abstract: One of several common water conserving techniques is on-site stormwater harvesting for non-drinking purposes. However there is a lack of knowledge on the actual cost-effectiveness and performance optimisation of any stormwater harvesting system. At present stormwater harvesting systems are proposed and installed without any in-depth analysis of its effectiveness in various climate conditions. In particular the proposed design storage volume could be overestimated or underestimated. The biggest limitation of stormwater harvesting schemes is the rainfall variability, which will control the size of the storage needed and can't be based on long-term average annual rainfall data. A stormwater harvesting system designed considering average annual rainfall will not provide much benefit for a critical dry period. Similarly, a stormwater harvesting design for a particular region will not be similar for stormwater harvesting design in other regions. With all these uncertainties, even with several awareness campaigns and financial incentives, there is a general reluctance to adopt any potential stormwater harvesting measure. The main reasons behind this are that people are not aware of the payback period for their initial investment and the optimum size of the storage required satisfying their performance requirements. It is necessary to quantify the expected amount of water that can be saved and used through any particular harvesting technique based on contributing catchment size, tank volume, geographic location, weather conditions and water demand.

eTank was developed based on daily water balance analysis, incorporating daily rainfall, contributing roof area and runoff generated from roof after losses (leakage and/or evaporation), daily water demand, tank storage capacity and overflow from the tank. Earlier eTank has been used for several reliability analyses within Melbourne metropolitan area to show ranges of rainwater tank outcomes depending on spatial and climatic variability. In order to assess reliability of domestic rainwater tanks in augmenting partial household water demand in Sydney area, the developed tool was used for three different climatic conditions (i.e. dry, average and wet years). In the earlier studies, a single representative year was selected for each of the dry, average and wet years. Dry, average and wet years were defined for the years having an annual rainfall of 10 percentile, 50 percentile and 90 percentile values respectively. However, as a particular year may have an unusual rainfall pattern, this study considered five respective years for each of the dry, average and wet years. eTank was used for the selected five years and average outcomes of five years were calculated. It is found that in some cases selection of a single year as dry/average/wet year lead to erroneous outcomes, as in some cases a particular dry year turned out to be better than a particular average year due to the fact that the selected average year was having some sporadic burst of rainfalls for which the storage capacity was insufficient.

To assess the spatial variability, the model was used for the performance analysis at two different regions of Sydney (Australia); Central and Western. These two regions of Sydney are characterised by notable different topography and rainfall characteristics. Rainwater tank outcomes (cumulative water savings, cumulative townwater supply and cumulative overflow) were presented and compared for these two regions for different climatic conditions.

Keywords: *Rainwater tank, daily water balance, climatic conditions, eTank*

Reliability analysis of household rainwater harvesting tanks in the coastal areas of Bangladesh using daily water balance model

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Abstract: Rooftop rainwater harvesting has received an increased attention as a potential alternative water supply source both in the coastal and arsenic affected areas of Bangladesh. Over the last several years, projects have been undertaken to promote and install both household and community based rainwater harvesting systems in order to mitigate drinking water problem both in the coastal and arsenic affected areas in the country. The annual average rainfall is the coastal area of Bangladesh is more than 2400 mm and rainwater harvesting has been practiced for a long time for drinking water supply. For household rainwater harvesting, the capacity of the storage tanks are 1000 to 5000 liters, provided under several projects of government and donor agencies. The optimum storage volume required by a household has not been investigated considering family size and demand, roof types and rainfall. As a result, most of the households can avail water from rainwater tanks for about 6 months and rest of the year, they have to depend on other unreliable and distance sources like pond or pond sand filter (PSF) water.

With the aim of assessing the currently used household rainwater harvesting system in the coastal areas of Bangladesh, design curves for the storage volume were developed for three climate conditions (i.e. dry, average and wet years) considering available roof catchment area (10 to 50 m^2), generated runoff and household demand (2 to 12 lpcd) for a typical family of 6 members using mass curve. From the historical daily rainfall data over 10-years period from 1998 to 2007, three separate climate conditions were selected based on annual rainfall. Years corresponding to minimum and maximum annual rainfall were considered as dry and wet year, respectively. The average year was considered the year having annual rainfall closed to the average annual rainfall over 10 years' period. Moreover, spreadsheet based daily water balance model was developed considering daily rainfall, contributing roof area and generated runoff from the roof catchment area, storage (tank) volume, water uses and overflow from the tank to assess the reliability of the currently used water tanks (1000 to 5000 liters).

The analysis showed that the currently used rainwater tanks in the coastal areas of Bangladesh are insufficient to meet the yearly drinking and cooking water demand. Under wet and dry climate conditions; the maximum achievable reliability is about 70%. The maximum reliability that can be achieved under average climate condition varies from 70 to 90% and the reliability does not increase significantly beyond 3000 L tank volume. A large quantity of water is lost as spilled water even with a tank size of 5000 L. This water can be used for other purposes if larger tanks are used to capture the excessive spilled water. This analysis also showed that although a huge amount of water is lost as spilled water, a significant amount of water would need to be collected from other sources like pond or PSF water during non-availability of water into the storage tanks. This water volume depends on tank size and reliability, an increase in tank size decreases the water volume collected from other sources. With increase of reliability, the water required to be collected from other sources also decreases.

Keywords: *Water balance model, reliability, rainwater harvesting, coastal area of Bangladesh*

Water quality investigation in the Hawkesbury-Nepean River in Sydney using Principal Component Analysis

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Abstract: The Hawkesbury-Nepean River System (HNRS) is an icon of Australia's largest city Sydney. Although there are a number of dams and in-stream structures throughout the river system, the HNRS is considered to be an unregulated river. Since European settlement, the HNRS has been used as a primary water source to meet the drinking water needs for over 80% of Sydney's population. The fact that it is located in the peri-urban areas dictates that it receive pollutants from a number of sewage treatment plants, located within the catchment, and the storm water runoff from agricultural and urban lands. Sydney Catchment Authority regularly monitors the water quality of the HNRS which generates a large three dimensional (different sampling stations and different parameters over time) data set containing useful information on pollutant build up and washoff on/from this river system.

In this study, factor analysis was used to identify the most significant water quality monitoring station(s). It was found that the three principal components explained more than 90% of the total variance in the data set. Moreover, this study showed that the dimensionality of the water quality parameters can be reduced to eight principal components which explained more than 70% of the total variance. Information obtained in this study can be used to design an optimal sampling strategy, which could reduce the number of sampling stations in the river system. However, further study is needed to confirm this initial finding.

Keywords: *Hawkesbury-Nepean River, principal component analysis, factor analysis, water quality*

Challenges for including error updating in real-time hydrological error models

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Abstract: Accurate and reliable quantification of uncertainty in hydrological models promises to make real-time streamflow predictions both more accurate and more useful. One simple but effective approach to quantifying hydrological uncertainty is to apply an error model to streamflow simulations. An error model collates errors from all sources into prediction errors and builds up a statistical model of the error time series. Streamflows are often highly auto-correlated, and updating real-time hydrological error models with information from recent observations is an obvious means to improving the accuracy of the predictions. We attempt to include an error updating component in a two-stage error model. In Stage 1, we use a logarithmic hyperbolic sine transform to normalise both simulated and observed time series and stabilize variance. A bias-correction component is introduced to correct the bias of transformed simulations. In Stage 2, we apply an error updating procedure to the simulations obtained from Stage 1 by using the information from the previous time step. The error updating is based on the auto-correlation of hydrological errors. All model parameters in both stages are assumed to be seasonally dependent, because hydrological models often perform differently for different seasons. The residual term from both stages are assumed to be Gaussian. Stage 1 only uses the information from the present time step and can be applied without Stage 2, while Stage 2 relies on Stage 1 and requires information from the previous time step.

We test the error model on hydrological simulations of four catchments generated with a conceptual daily rainfall-runoff model. In isolation, Stage 1 leads to similar or marginally more accurate predictions than the original hydrological simulations. The Stage 1 uncertainty estimation is generally reliable. Applying the error updating model (Stage 2) markedly improves the accuracy of Stage 1 simulations. However, we show that the uncertainty in the Stage 2 simulations is no longer reliably quantified after the error updating is applied. This is associated with our assumption that the residual term is Gaussian. After applying the error updating, most residuals in the error model are significantly reduced, while a few residuals remain. This causes the distribution of residuals to have a longer tail than a Gaussian distribution.

The two-stage estimation of hydrological prediction uncertainty is shown to be simple but effective. The prediction accuracy is progressively improved after bias correction in the transform domain (Stage 1) and error updating in original domain (Stage 2). However, it remains challenging to offer reliable uncertainty estimation after including error updating. We recommend replacing the Gaussian distribution with more sophisticated distributions in the error model.

Keywords: *Uncertainty estimation, error model, hydrological prediction*

Probabilistic flood hydrographs using Monte Carlo simulation: potential impact to flood inundation mapping

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Abstract: Flood inundation modelling generally involves two steps. The first involves the use of a hydrologic model, such as RORB, to estimate the design flood hydrograph for a given design storm event. These models require several inputs, such as design rainfalls (i.e. duration, intensity & temporal pattern), losses, baseflow and routing parameters; each of which has an associated degree of uncertainty that can affect the shape and magnitude of the estimated design flood hydrograph. The second involves the use of these design flood hydrographs as inputs into a hydraulic model, to estimate the flood inundation extent. Given the uncertainties in hydrologic modelling and their importance in mapping inundation extents, it is of interest to determine the potential impacts of hydrological uncertainties on flood inundation mapping. This paper, therefore, considers how the uncertainties in design losses can affect the hydraulic analysis.

The Orara River catchment in north-east NSW was selected for this study, which covers an area of 135 km^2. The data during the period of 1970 to 2009 was used, with both streamflow (204025) and a pluviograph station (59026) available throughout this period. For 43 storm events, rainfall spatial patterns are produced using ordinary kriging, with 23 daily rainfall stations, and baseflow was separated using a recursive digital filter. The RORB rainfall-runoff model was adopted, with the non-linearity exponent fixed at 0.8 and the routing parameter fixed at 15.

Both the initial and continuing losses were calibrated for each event and then examined to find the best fit probability distribution. From the 27 parametric distributions, it was found that the initial loss (IL) can be approximated by the 2-parameter Gamma distribution and the continuing loss (CL) can be approximated by the 3-parameter Weibull distribution. A Monte Carlo framework was adopted to quantify uncertainties in the losses. Ten thousand randomly generated initial and continuing loss values were run through RORB in order to derive confidence limits for the peak flow, flood volume and time to peak flow characteristics. These derived flood frequency curves (DFFC) are then compared to observed floods and an at-site flood frequency analysis (FFA).

The median relative errors of the DFFC when compared to the at-site FFA were found to be 13.5% and -23.1%, for the peak flow and flood volumes, respectively. The flood volumes were found to be more consistent across all probabilities with a range of -3.6% to -26.6%, as compared to the peak flows that ranged from 9% to 39.5%. The confidence band (referring to the 5th and 95th percentiles) were found to be smallest about the time to peak flow, which only varied up to 10%, followed by the peak flows which showed around ±55% variability. The flood volumes saw the widest confidence bands, with a median variation of about ±63%, which increased to a maximum of about ±105%.

It has been found that the Monte Carlo framework adopted in this study has the ability to produce more accurate and realistic design flood estimates, however, these improvements have not yet been carried through to the hydraulic model. Flood inundation maps are generally still depicted as a single deterministic flood inundation prediction for a given deterministic design hydrograph. As found in a study by Merwade et al. (2008) when the standard errors in peak flows ranged from -36.1% to 56.5%, this caused a shift in the water surface elevation from -0.4 m to 1 m and the extent of floodplain inundation varied in width from 54.3 m to 90.2 m. With peak flows ranging up to ±55% in this study, potentially causing these types of errors in the inundation extents, it is clear that probability-weighted flood inundation extents need to be modelled rather than a single deterministic prediction.

Keywords: *Monte Carlo simulation, rainfall losses, probability distribution, flood risk*

Analysing lagged ENSO and IOD as potential predictors for long-term rainfall forecasting using multiple regression modelling

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Abstract: Several climate indices around Australia were found to have strong correlations with south-east Australian seasonal rainfalls. Any such correlation with lagged climate indices and seasonal rainfall afterwards can be used for forecasting long-term seasonal rainfall. In this study, long-term forecasting of Victorian spring rainfall has been investigated using lagged El Nino Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) indices using multiple regression analysis. Three stations of Buchan (east VIC), Malmsbury (Central VIC) and Kaniva (West VIC) were chosen as case study. Rainfall was classified according to El Nino, La Nina and Neutral years of ENSO, and also positive and negative years of IOD. It was discovered that categorizing rainfalls based on the years of ENSO and IOD do not have significant effect on its relationship with these climate modes. It was also found that the Pearson correlation coefficient between ENSO and Buchan in east Victoria is very weak; for Malmsbury and Kaniva ENSO indicators are showing higher correlations compared to Buchan. DMI effect is stronger in these two regions as well.

Using the non-classified rainfalls, correlation coefficient between spring rainfall at year *n* and Dec_{n-1}-Aug_n monthly values of ENSO and IOD indicators (Nino3.4, SOI and DMI) were calculated ("*n*" being the year for which spring rainfall is being predicted); It was discovered that only the three months of June, July and August of Nino3.4, SOI and DMI have significant correlation with spring rainfall. Several multiple regression models were investigated using lagged ENSO and IOD as potential predictors of spring rainfall; the models that satisfied the limits of statistical significance and multicollinearity were used to forecast spring rainfall three consecutive years in advance. Multiple regression analysis showed poor results in regards to forecasting ability in east Victoria, however it was able to forecast spring rainfall three consecutive years in advance for central and west Victoria with a correlation of 0.48 and 0.67 respectively.

Keywords: *Rainfall, El Nino Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), multiple regression model*

Capability of Artificial Neural Networks for predicting long-term seasonal rainfalls in east Australia

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Abstract: Rainfall in southeast Australia is known to be affected by large scale climate modes variability. This study focused on investigating the use of lagged El Nino Southern Oscillation (ENSO) as potential predictors of spring rainfall in Victoria and Queensland in east Australia. Six rainfall stations including Bruthen, Buchan and Orbost in Victoria and Barcaldine, Kalamia and Augathella in Queensland were chosen as case study. Artificial Neural Network (ANN) approach was used as a nonlinear technique to capture this complex relationship. The Pearson correlation coefficients of past values of ENSO with spring rainfalls were calculated; it was discovered that the three months of June, July and August of Nino3.4, have significant correlation with spring rainfall. These correlations are very weak for Victoria and relatively higher for Queensland. These lag months of ENSO were incorporated into ANN models; i.e. the set of Nino3.4 $_{\text{(Jun-July-Aug)}}$ was used as inputs for developing ANN models for the stations in Victoria and Queensland. Multilayer Perceptron (MLP) architecture was chosen for this purpose. The models were trained based on Levenberg-Marquardt algorithm. ANN models showed higher correlation for Queensland compared to Victoria indicating that ANN is more capable of finding the pattern and trend of the observations in Queensland.

After calibrating and validating the models, in order to evaluate the generalization ability of the developed ANN models, out-of-sample tests were carried out. It was discovered that ANN models are showing very poor generalization ability for east Victoria regarding finding the pattern of the series (r = -0.97, 0.23 and -0.67 for Bruthen, Buchan and Orbost respectively) compared to Queensland with correlation coefficients of 0.74, 0.100 and 0.98 for Barcaldine, Kalamia and Augathella respectively. This study shows the ability of ANN in finding nonlinear relationships between complex large scale climate models and rainfalls in south-east Australia.

Keywords: *Artificial Neural Networks (ANN), rainfall, forecast, El Nino Southern Oscillation (ENSO)*

Monthly forecasts of catchment rainfall to long lead times using GCM rainfall and SSTs

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Abstract: User surveys conducted by the Bureau of Meteorology reveal that streamflow forecasts at monthly temporal resolution and with lead times of up to 12 months are highly desirable. A convenient approach to produce such forecasts is to downscale rainfall forecasts from coupled ocean-atmosphere general circulation models (GCMs) and use the downscaled rainfall to force one or more hydrological models. However, the use of GCM rainfall directly in hydrological models is problematic for a number of reasons.

The main problem with raw GCM rainfall forecasts is that the forecasts suffer from systematic biases, and the rainfall is therefore not suitable for input to a hydrological model that has been calibrated against observed data. Also, ensemble forecasts often do not have sufficient spread in the ensembles, leading to underestimation of forecast uncertainty. Another problem with raw GCM rainfall relates to spatial resolution. The GCM grid cell area can often be many times larger than the catchment area. Thus GCMs are sometimes unable to capture the effect of topography on rainfall. Despite the complexity of GCMs, overall rainfall forecasting skills remain low.

In this study, we use monthly rainfall and sea surface temperature (SST) data from the Predictive Ocean Atmosphere Model for Australia (POAMA) GCM as predictors in Bayesian joint probability (BJP) models to (re)forecast catchment rainfall. The BJP models relate the predictors to observed rainfall and output ensemble forecasts. Bayesian model averaging (BMA) is used to merge the forecasts from the multiple models. This approach is designed to overcome the aforementioned problems with raw GCM rainfall and has the potential to increase forecasting skill through the use of SST information. The approach is tested on 36 catchments of various sizes in eastern and southwestern Australia for forecasts with 0 to 6 months lead time.

Forecasts for the period 1980-2010 are assessed using leave-one-year-out cross validation. Although skills are generally low, in some catchments, moderate skill scores are observed for lead times of up to 6 months. The forecasts are seen to source skill from both the atmospheric and ocean modules of the GCM. Indeed, including SST-based models in the BMA can enable substantial improvements in skill compared to including only raw rainfall-based models. The forecasting approach produces overall unbiased forecasts. Visual assessment of attributes diagrams shows that the forecasts are acceptably reliable when interpreted as probabilities of exceeding the climatological median. This suggests that the forecast ensemble spreads are generally appropriate, and not too narrow or too wide. In months and catchments where there is limited skill, the forecasts revert to climatology.

In our Bayesian approach, a separate model is used to downscale rainfall at each lead time. Therefore, temporal relationships between ensemble members are not maintained across lead times. To establish the temporal relationships, we apply a pragmatic technique known as the Schaake Shuffle to link ensemble members. Each ensemble member can therefore be considered as a timeseries forecast of rainfall. Shuffled forecasts are also suitable for aggregation, e.g. to seasonal forecasts.

The forecasts developed in this study are overall unbiased and have appropriate ensemble spread. They are therefore suitable for forcing a hydrological model such as the monthly Water Partition and Balance Model (WAPABA) that has been calibrated against observed data. The statistical approach is applicable to any size catchment.

Keywords: *Rainfall, downscaling, forecasting*

A stochastic weather generation method for temporal precipitation simulation

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Abstract: Disaggregation methods are designed to produce finer temporal scale data from coarser temporal scale data. An example of this need is the modification of monthly scale precipitation data to drive dynamic hydrological models operated at daily scale. Such issues occur for dynamic hydrological forecasts in which the General Circulation Models (GCMs) are used to generate the required precipitation data but the GCM outputs are only be reliable at coarser temporal scales. Stochastic weather generation methods together with simple adjustment of the total amounts provide a simple and efficient way for data disaggregation. However, the success of stochastic weather generation depends critically on whether the chain-dependent process can mimic the transient property between dry and wet days and whether the specified statistical distribution for amounts on wet days can capture the distributional properties of the amounts. Note that there are many small precipitation events within the catchment data which are treated differently for different purpose. Simple elimination by using different threshold values to define dry/wet days was frequently used in practice. A single statistical distribution may not be sufficient to capture the characteristics of amounts on positive data. Furthermore, the performance of dynamic hydrological model depends also on whether the specified statistical distribution for amounts can capture large precipitation events. Various proposals have been developed to better capture the precipitation pattern, including the use of high-order Markov Chain model for the occurrence pattern and the use of a mixed distribution for the amounts.

In this paper, a hybrid stochastic weather generation method is proposed to simulate daily precipitation data based on the monthly data at catchment scale. Firstly, a multiple state Markov chain model is used for occurrence pattern as two state model may not reflect different weather patterns. Secondly, a truncated Gamma distribution is used for smaller precipitation amounts as usual and a censored extended Burr XII distribution is employed for larger amounts as it can better capture the extreme values. By doing this, one needs not deal with discontinuity in the distribution of precipitation amounts and ensure that the state and its corresponding amount are well matched. In order to take account of seasonality, the models are constructed for individual months.

The proposed method is demonstrated by using catchment data from different climatic regions in Australia. Results show that

(1) The proposed multiple state Markov chain model can capture the states reasonable well;

(2) The seasonality is an important factor to be considered in the disaggregation;

(3) The proposed distributions for different states can mimic the amounts well.

As an regression based approach for the occurrences and distribution fitting approach for the amounts, the proposed method can be easily extended to include external predictors for generalization and/or improvements.

Keywords: *Censored Extended Burr XII distribution; Markov chain model; stochastic simulation; truncated Gamma distribution*

Regionalisation of water savings from rainwater harvesting system in Greater Sydney

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Abstract: Rainwater harvesting is becoming popular in Australian cities. Often, a standard tank size is recommended by local authorities; for example in Sydney, a 3kL tank is recommended for detached houses by NSW Government as per BASIX regulation. This paper investigates the performance of a rainwater harvesting system in saving water using data from 162 different locations in Greater Sydney region. A combination of toilet, laundry and irrigation use is considered for three different tank sizes of 2kL, 3kL and 5kL. It has been found that the water savings in Greater Sydney region ranges from 38 kL to 47 kL for a 2kL tank size, 46 kL to 57 kL for a 3kL tank size and 55 kL to 77 kL for a 5kL tank size. It has also been found that a 5 kL tank is preferable to 2 kL and 3 kL as this can offer 20% to 64% more water savings. It has also been found that water savings vary notably at different locations across the Greater Sydney region, and hence a blanket recommended tank size may not be appropriate for the whole of Greater Sydney.

***Keywords**:* *Water balance model, rainwater harvesting, rainwater tanks, tank reliability, water recycling*

EXTENDED ABSTRACT ONLY

Dynamic seasonal streamflow forecasting approach – Evaluation of rainfall runoff model performances

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Abstract: The Bureau of Meteorology has recently published an article, tilted 'Experimental Evaluation of the Dynamic Seasonal Streamflow Forecasting Approach' where evaluation of the performances of the dynamic modeling approach were reported for eight key water supply catchments in the southern Murray Darling Basin. The evaluation was done for the (Upper Murrumbidgee) Cotter River at Gingera, Murrumbidgee River above Tantangara Reservoir, Queanbeyan River at Tinderry, Goobarragandra River at Lacmalac, (Upper Murray) River Murray at Biggara, and Mitta Mitta River at Hinnomunjie, (Upper Goulburn) Dohertys and Taggerty. Three widely used rainfall runoff models, Sacramento, SIMHYD, and SMAR along with downscaled rainfall data from POAMA 1.5 in ensemble mode were used for this experimental evaluation. The models were calibrated and validated in historical mode with observed rainfall data while retrospective forecasting was performed with downscaled POAMA rainfall data. As shown by the Nash-Sutcliffe Efficiency (NSE), except Tinderry and Hinnamunjie, the three models showed good performance for both the calibration and validation periods in all other catchments. The NSE for calibration and validation periods from SIMHYD varied in the range of 0.52 to 0.94 and 0.61 to 0.91, respectively. Also, with Sacramento, the NSE for calibration and validation periods varied in the range of 0.71 to 0.95 and 0.70 to 0.93, respectively.

The primary focus of this study was to investigate the possible factors that may have contributed to the different model performances among the catchments during calibration and validation of the rainfall runoff models, SIMHYD and Sacramento. The rainfall runoff model that performed better produced a good fit to the calibration and validation dataset. This study also attempted to understand the level of accuracy in the partitioning between surface water runoff and groundwater flow at the catchment outlet. The catchment rainfall-runoff variability, flow duration curve statistics, and baseflow indices were used as indicators in this study. These indicators were calculated for the observed and simulated streamflow data and then compared. The rainfall-runoff variability was evaluated for monthly data through the coefficient of variation (C_v) which is the ratio of the standard deviation and mean. The estimated monthly values of Q20/Q90 (a measure of stream flow variability), Q50/Q90 (indicator of the level of variability of low flow discharge), Q90/Q50 (indicator of the proportion of stream flow originating from groundwater store) and percent zero flows were used as the flow duration curve indices. The digit filter developed by Lyne and Hollick was used in this work to separate baseflow from observed runoff during the calibration and validation. The C_v varied in the range of 0.50 to 0.79 for observed rainfall and 0.86 to 2.30 for observed runoff with the highest estimated values were for Tinderry. The flow duration statistics indicated relatively low flow conditions, high level of variability in stream flow and low flow, and low level of contribution of groundwater flow to stream flow at Tinderry. In regard to baseflow indices with observed data, the lowest baseflow index was noted with Tinderry confirming its low groundwater flow contribution. Overall, relatively high baseflow indices were indicated with the modelled results in comparison to that derived from the observed data, which could be either due to model structure or due to NSE based objective function used in model calibration or both.

Results indicated that surface water and groundwater partitioning provided by the SIMHYD and Sacramento models were not comparable to that obtained from the observed baseflow separation techniques. The baseflow indices of modelled data may be improved further by using model structure that is more responsive to baseflow characteristics inferred from observed data. The results also indicated that high rainfall and runoff variability and low flow conditions relative to other catchments may have been major contributory factors for the low model performances with Tinderry catchment. The study did not provide any clear indication of the reasons for low model performance in the Hinnomunjie catchment, which in part may be due to the effects of snowpack in late winter and early spring and absence of snowmelt component in the hydrologic models used in the study.

***Keywords**:* *Dynamic modelling, model performance, baseflow, surface water, groundwater, partitioning*

Prediction of dissolved organic matter (DOM) fractions removal from surface water using high performance size exclusion chromatography

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Abstract: Drinking water of high quality is an essential for human welfare and preserving good health. The removal of dissolved organic matter (DOM) may be necessary to achieve high quality drinking water. The concentration of DOM in drinking water may vary and its removal can be optimized by optimization of coagulant dosing and coagulation pH. The treatability of organics by coagulation depends on the type and dose of coagulants. General water quality parameters such as UV absorbance, colour and turbidity have been used in many coagulation modeling approaches for DOC removal (Kastl et al., 2004; van Leeuwen 2005, 2009; Daly et al., 2007 Xie et al., 2012). However, these water quality parameters provide limited information on the character of DOM. To assess the treatability of DOM, suitable analytical techniques or modeling tools are needed to obtain comprehensive and improved information of the character of removable and non-removable DOM in raw and treated waters. In this study, investigation was conducted on data obtained from high performance size exclusion chromatography (HPSEC) followed by peak fitting (a commercially available software, Peak fit Version 4, Systat Software Inc.) to model and predict DOM fractions removable by coagulation. River Murray source water (collected from Echuca, Wentworth and Morgan) and Myponga Reservoir water were resin fractionated before and after coagulation using DAX-8 resin that fractionated the DOM into a sorbed DAX-8 fraction (SDF) and non-sorbed DAX-8 fraction (NSDF). Jar testing was performed using an enhanced alum coagulation dose and a dose for maximum removal of organics at a controlled pH of 6 (Chow et al., 2009; Drikas et al., 2011). Using raw water collected from River Murray and Myponga Reservoir, water quality parameters such as pH, UV abs 254nm, colour, DOC and HPSEC of resin fractionation samples before and after coagulation were recorded. The main focus of this study was to:

- Determine the removal of DOC in relation to its character by using enhanced coagulation doses.
- Determine the potential of using peak fitting to analyse HPSEC data and to predict the treatability of removable and non-removable DOM fractions.

By comparing the HPSEC molecular weight profiles of the raw and treated waters, it was found that low molecular weight organics were not effectively removed by alum even after using a very high dose. A peak-fitting model was developed based on the apparent molecular weight profile of DOM present in raw water. This model was further applied to assess and predict DOM treatability by determining the percentage areas of the peaks that were assigned to easily removable, maximum removable and non-removable organics. The removal prediction of DOM was compared with the actual dissolved organic carbon (DOC) removed determined by conventional jar testing. This technique was assessed by further jar testing of different water samples collected from various locations of River Murray. It is concluded that predictions of removable and non-removable DOM fractions by coagulation and resin fractionation using this peak fitting technique were found to be within 10% of actual values. The basis of this study was to establish a suitable tool, using resin fractionation and HPSEC data for rapid prediction of coagulable DOM fractions. Here, we report the development of a model specifically designed for HPSEC peak fit data of raw and treated water by coagulation and resin fractionation, to enable prediction of the percentage DOC removal.

Keywords: *Fractionation, HPSEC, Peak fitting, Modeling*

Data Driven Statistical Model for Manganese Concentration Prediction in Drinking Water Reservoirs

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Abstract: Continuously monitoring and managing manganese (Mn) concentrations in drinking water supply reservoirs are paramount for water suppliers, as high concentrations create discoloration of potable water supplied to the customers. Traditional Mn management approaches typically involve manual sampling and laboratory testing of raw water from supply reservoirs on a regular basis (typically weekly) and then treatment decisions are made based on the soluble Mn level exceeding an allowable threshold level; for the reservoir in this study the threshold level for treatment is 0.02 mg/L. Often Mn testing is conducted all year, but in the sub-tropical regions, such as the Gold Coast, Australia, where the reservoir of interest for this study (Hinze Dam) is located, high Mn concentrations only occur for a brief period during the dam destratification process which occurs at the beginning of winter. High concentrations of Mn, resulting from the destratification event, in water entering the water treatment plant are usually treated through pre filter chlorination for concentrations < 0.18 mg/L, or with addition of potassium permanganate for higher concentrations.

Recently, a vertical profiling system (VPS) has enabled the data collection of many water parameters, such as water temperature, dissolved oxygen, pH, conductivity and redox potential every 3 hours. Despite the abundance of physical and water quality data collected by the VPS, it cannot directly measure a range of water quality parameters such as Mn, thus manual sampling and testing are still required.

Since previous studies have shown significant links between the physicochemical parameters collected by VPS and Mn concentrations, a data driven model can be developed to predict Mn values accurately. A Multiple Linear Regression (MLR) with empirical equations for Hinze dam was trained using data from 2008 to 2011, and tested with an independent dataset from 2012. The model was able to predict one week ahead the average Mn concentration in the epilimnion, where the water is drawn, with a correlation coefficient higher than 0.83. The output is also displayed in form of probabilities of exceeding certain thresholds, for instance 0.02 mg/L (namely Mn treatment needed).

Successfully achieving the development of an autonomous and accurate tool for the data mining of VPS parameter datasets to predict levels of Mn provides several benefits for treatment operators: such a decision support system (DSS) would significantly reduce laboratory costs while concurrently enhancing treatment adaption response times.

Keywords: *Manganese, Decision Support System, Vertical Profiling System, Reservoir Destratification, Water Treatment*

CatStream: An Integrated Catchment-Stream Water Quality Model

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Abstract: Water quality modelling is the primary tool used for catchment and stream water quality investigations. The general architecture of a typical water quality model is the integration of the pollutant processes with the hydrologic and hydraulic approaches. However, due to the lack of specific local information and poor understanding of the limitations of various estimation techniques and underlying physical parameters, modelling approaches are often subjected to producing gross errors. Most of the available water quality models are too simple and/or stochastic in nature. Many of those models perform water quality estimations in isolation, i.e. separate water quality models for catchment and stream analyses. Isolated models may lead to inconsistencies and biased results in the prediction of water quality parameters. On the other hand, there are some integrated water quality models, which are very complex requiring huge physical and chemical data as well as determining many model parameters. This paper presents the development of a simple, integrated and deterministic catchment-stream water quality model to be able to continuously simulate different water quality parameters. The integrated model is comprised of two individual models: the catchment water quality model and the stream water quality model. The catchment water quality model consists of two sub-models: rainfall-runoff model and pollutant processes model. The rainfall-runoff model was developed by considering the time-area method of runoff routing. The model estimates amount of surface runoff generated from a specified catchment for which rainfall data is provided. Water quality parameters were incorporated with the developed rainfall-runoff model, which represents the catchment water quality model. This model estimates the amount of pollutant accumulated on catchment surfaces during the antecedent dry days, and their transportation with surface runoff into waterways and receiving water bodies throughout storm events. Similar to the catchment water quality model, the stream water quality model comprised of two sub-models: the stream flow model and stream pollutant processes model. The stream flow model was developed by considering the Muskingum-Cunge method of stream routing. The stream flow model estimates the rate of water flow into the downstream sections of a particular stream reach. The processes of the same water quality parameters as used in the catchment water quality model were incorporated with the stream flow model which represents the stream water quality model. Final output of the stream water quality model is the concentration of transported pollutants into different downstream sections of a particular stream reach. Finally, the catchment water quality model and the stream water quality model were integrated for the continuous simulation of previously mentioned water quality parameters. For calibration and validation of the model, different published data and reliable source data collected by the Gold Coast City Council (GCCC) were used. Calibration of the catchment water quality model and stream water quality model was performed separately. The calibration results demonstrated the suitability of the developed model as a tool to help with water quality management issues. The major advantage of the developed model is the easy and continuous simulations of water quality parameters associated with surface runoff during any rainfall event. The preparation process of the input data for the model is simple. The capability of the model to simulate surface runoff and pollutant loads from a wide range of rainfall intensities make the integrated model useful in assessing the impact of stormwater pollution flowing into waterways and receiving water bodies and to design effective stormwater treatment measures.

Keywords: *Integrated Model, water quality model, pollutant processes, calibration*

Application of second-order central composite design (CCD) for optimization of river water treatment using trivalent (alum) and quadrivalent (titanium tetrachloride) coagulants

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Abstract: Statistically designed jar test experiments are more feasible and time saving techniques to optimize the water treatment processes against the conventional jar experiments. Experimental designs normally should be replicated to achieve accurate valuation of the effects of input factors such as coagulant dose, coagulation pH and type of coagulant on the output responses i.e. removals of dissolved organic matter (DOM), turbidity and color. For this purpose, a response surface methodology (RSM) was applied using second-order central composite design (CCD) to optimize the treatment conditions at coagulant dose range 3.5-16.2 mg/L (equivalent to metal concentration) and pH range 4.5-8. In addition, the adsorption mechanism of organic (DOM) and inorganic (suspended clay particles) contaminants through the quadrivalent titanium tetrachloride was compared with the trivalent conventional coagulant, alum.

The isoelectric point (IEP), where the total charge is zero, of the titanium tetrachloride and alum were found to be at pH about 4.5 and 8, respectively through the zeta potential (ZP) values obtained at different pH. The ZP values of titanium and alum flocs tended to decrease as the pH values increased. The trend of alum (graph was not shown) indicated that ZP values of alum flocs were positive at pH < 6.5 whereas these values were reached to negative at pH ≥ 7 where the dominant removal mechanism is sweep coagulation. In contrast, the ZP of titanium flocs were negative at all pH levels tested, however this trend showed that there might be a possibility for the ZP values of titanium flocs to be positive at pH < 4.5 where the dominant mechanisms are both charge neutralization and adsorption. Experimental results showed that titanium salt was promising for the removal of DOM (about 55%) and turbidity (> 99%) at pH around 4.5-5 whereas color removal was about 93% at the same pH and at a coagulant dose of 10 mgTi/L. Adsorption mechanism of DOM was evaluated using three different isotherm models (BET, Freundlich and Langmuir); higher correlation coefficient of BET and/or Freundlich models indicated adsorption occurs in multilayer formation.

The designed jar tests were modelled using polynomial equations with the use of quadratic models for both coagulants. Based on adequate signals, these models were used to navigate the design space in accordance with ANOVA results. The final model equations in terms of coded factors can be written as follow:

Alum;

$$\text{DOM removal (\%)} = 53.4 + 13.4 (X_1) - 8.6 (X_2) + 0.3 (X_1)(X_2) - 3.1 (X_1)^2 - 4.6 (X_2)^2 - 5.7 (X_1)(X_2)^2 \quad (1)$$

$$\text{Turbidity removal (\%)} = 99.3 + 0.5 (X_1) - 0.1 (X_2) + 0.2 (X_1)(X_2) - 0.3 (X_1)^{2-} 0.1 (X_2)^2 - 0.5 (X_1)(X_2)^2 \quad (2)$$

Titanium tetrachloride;

$$\text{DOM removal (\%)} = 41.9 + 12.7 (X_1) - 7.9 (X_2) - 3.7 (X_1)(X_2) - 6.1 (X_1)^2 - 0.42 (X_2)^2 - 3.15 (X_1)(X_2)^2 \quad (3)$$

$$\text{Turbidity removal (\%)} = 98.8 + 0.7 (X_1) - 0.5 (X_2) - 0.9 (X_1)(X_2) - 0.4 (X_1)^2 + 0.1 (X_2)^2 + 0.2 (X_1)(X_2)^2 \quad (4)$$

Where, X_1 and X_2 are the coagulant dose (mg/L) and coagulation pH, respectively as experimental factors. The predicted R-squared values were in reasonable agreement with the adjusted R-squared values indicating the accuracy of predicted models for each response. In coagulation kinetics, the higher values of flocculation index and variance confirmed that titanium salt formed larger and more heterogeneous floc sizes than alum both at enhanced and sweep coagulation. After the breakage of formed flocs, titanium flocs alone showed greater floc strength than the flocs formed for alum. Increased the percentage of titanium in the blended ratio of Al:Ti resulted in larger size flocs with higher strength than the alum alone. Based on our experimental findings, it can be concluded that CCD-RSM is a useful statistical design to optimize the water treatment process and the titanium salt can be used as an alternative coagulant for high turbid surface waters, assuming all health related requirements are met with the use of titanium tetrachloride.

Keywords: *Central composite design, coagulation, dissolved organic matter, titanium tetrachloride*

Modelling Pollutants Transport and Degradation through Wetlands

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Abstract: Wetlands play a number of roles in the water environment, principally water purification, flood control, and groundwater replenishment. In addition to these benefits, United Nations Millennium Ecosystem Assessment and Ramsar Convention defined wetlands to be of biosphere significance and societal importance in the areas of shoreline stabilisation, storm protection, cultural values, recreation and tourism, and climate change mitigation and adaptation. Wetlands are also considered the most biologically diverse of all ecosystems, serving as home to a wide range of plant and animal life. The function of most natural wetland systems is not to treat wastewater, however, their high potential for the filtering and the treatment of pollutants has been recognized by environmental scientists who specialize in the area of wastewater treatment.

In the past wetlands used to be in place naturally and used to provide ecological benefits to the mankind and environment. Through recognizing their immense benefits, human being started to construct artificial wetlands. Recently, constructed wetlands are recommended as one of the salient features of water sensitive urban design, which play an important role in water management and ecologically sustainable development. These constructed artificial wetland systems are highly controlled environments that intend to mimic the occurrences of soil, flora, and microorganisms in natural wetlands to help in treating wastewater effluent. Artificial wetlands provide the ability to experiment with flow regimes, micro-biotic composition, and flora in order to produce the most efficient treatment process.

Constructed wetlands are increasingly being designed and used to treat wastewaters. Majority of constructed wetlands are designed based on steady-state releases of pollutants loading. However, in some cases (i.e. aquaculture ponds) pollutant loadings are not steady-state, rather are intermittent. Pollutants transport analysis based on steady-state release (inflow) will be quite different from an analysis based on intermittent loading/inflow. In the past several studies were conducted on pollutants transport and degradation through wetlands using steady-state inflow of pollutants. In this paper, a simple numerical model is proposed and developed based on conservation of mass principle for the pollutants and transport through a wetland, considering a series of tanks. Tank-in-series approach assumes that the wetland is comprised of several interconnected tanks, each of which can be modeled as a continuous flow stirred tank reactor. As for pollutants, in this study organic matters are considered. Same numerical model can be used for different organic matters, considering different values of degradation rate. Using first-order kinetic equations of pollutants transport and degradation and applying Euler's method of difference equations a numerical model was developed. Developed numerical model can simulate pollutant transport and degradations for steady-state, continuous and/or irregular/intermittent pollutant loadings. Numerical model results were verified with earlier developed analytical solutions for intermittent pollutant loadings, which were applied for aquaculture ponds in Texas (USA). Numerical model results are close to the results derived from analytical solutions for the same condition. Reasons of some primary discrepancies are discussed. Developed numerical model was used to present different scenario using different flow rates, pond volumes and different masses of intermittent pollutants. It is found that all of these parameters have significant impact on outflow pollutants' concentrations.

Keywords: *Intermittent loading, tanks-in-series, wetland, conservation of mass and pollutants*

An MILP Model for Cost - Effective Water Treatment Synthesis

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Abstract: Water is a precious and scarce resource, essential for sustaining nature, human life and industry. Efficient water treatment is recognised as the only method to sustain safe supplies of water in the future. So far scientific work has focused solely on the performance optimization of individual water purification units due to overall process complexity. A whole - systems approach in the area will be of a significant benefit to industry by increasing overall process efficiency and decreasing plant costs.

This work addresses the current gap by considering synthesis of water treatment trains using mixed integer linear programming (MILP). The model accounts for the most common contaminants found in water, secondary treated wastewater, seawater or brackish water. Such major pollution indicators are chemical oxygen demand (COD), biochemical oxygen demand (BOD), total dissolved solids (TDS), total suspended solids (TSS), turbidity and coliforms. The water source is treated to meet potable, process or reclaimed water standards. The set of candidate steps is selected to reflect the most extensively utilised industrial processes such as coagulation-flocculation, membrane filtration and UV disinfection at various operating conditions. The overall number of trains is minimised based on efficiency removal factors and final water purity specifications. The former takes into account the physicochemical properties of the contaminants and the respective regression models for rejection or retention of an addressed impurity in a certain candidate.

A particular case of desalination for drinking water supply is studied. The model is tested for the standard level of contaminants in seawater, TDS and TSS, to be removed by a set of up to 34 candidate trains. For production of ca. 600 m^3/h water the model identifies an optimum solution of overall 6 trains consisting of ultrafiltration (UF), nanofiltration(NF) and reverse osmosis (RO). The objective function minimised is the annual operating cost as a function of pumps electricity consumption, membrane cleaning and replacement practices. Overall, the results obtained agree with the recent trends in industrial desalination process synthesis and hence, the model can provide a valuable guidance in water purification processes design.

Keywords: *Water purification, MILP, efficiency removal factors, operating cost*

Three-dimensional Investigation of Retention Time Distribution of Waste Stabilisation Ponds

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Abstract: Waste stabilisation ponds (WSPs) use natural microbiological, photosynthetic, biochemical, physico-chemical and hydrodynamic processes to treat wastewater. They require little technical attention during operation and are less demanding in terms of construction cost and energy consumption than other engineered wastewater treatment systems. Practical engineering experience and research over the past few decades have established that hydrodynamics is crucial in determining the treatment efficiency of WSPs. After reviewing a large number of pond systems operated in Australia, Wood et al. (1995) stated that many systems were found to operate below an optimal level due to a reduced retention time of wastewater. It is therefore required that the hydrodynamic retention time distribution be precisely understood so that the hydrodynamic behaviour and the overall treatment efficiency of WSPs can be accurately evaluated.

A substantial number of models have been developed to look into various hydrodynamic aspects of WSPs. However, most of the work has been limited to one or two dimensions due to computational capabilities. The present study aims to establish a generic model fully describing the three-dimensional hydrodynamic behaviour of WSPs. MIKE by DHI is chosen as the modelling tool considering the following favourable features: (1) applying a non-hydrostatic engine to simulate unsteady three-dimensional flows; (2) taking into account density variation, bathymetry and external forces such as meteorology, tidal events and currents; (3) incorporating several modules such as hydrodynamic, transport and ecological, which allows integrated modelling of hydrodynamic and biological processes for a more complete analysis and prediction of wastewater treatment.

A typical pond model with the dimensions of 50 m (length) by 20 m (width) by 1.5 m (depth) was adopted. The model was validated against an empirical formula for the wind-driven circulation in a tank. An optimised meshing scheme of 1 m by 1 m horizontally and 7 layers vertically was determined to achieve the best computational performance-time ratio. Subsequently, the validated model was employed to formulate WSP retention time analysis.

A parametric study was conducted in terms of varying length to width ratio (L/W), inlet/outlet positioning, inlet direction changes, varying wind speed and direction. It was found that:

- Pond L/W ratio has a significant influence on pond retention time. It was noted that a larger L/W ratio is associated with longer retention time.
- Winds are a predominant factor in WSP performance, especially wind direction. The retention time of wastewater was found to be longer due to the circulation in the transverse direction generated in the pond when wind direction was perpendicular to the inflow direction.
- The inlet/outlet position change and the inflow direction variation present a rather mild influence on pond retention time in comparison to pond L/W ratio and winds. This is partially due to the local boundary effect in the modelling. Another possible reason can be associated with the pond configuration specified in this study.

This study performs a systematic investigation of WSP retention time based on three dimensional models. It is expected to establish a modelling framework for extended WSP studies. The parameter analysis presented in this work will be further developed to address the interrelated effects of multiple parameters on WSP hydrodynamics. Ultimately, this study will lead to the development of a 3D model which will incorporate the fate of pathogens linked to hydrodynamic parameters. This model will allow overall efficiency evaluation of the design, operation, retrofit and maintenance of WSPs.

Keywords: *Three dimensions, numerical modelling, Waste Stabilisation Ponds, retention time distribution, hydrodynamics*

Modelling salt accumulation in an oval irrigated with recycled water

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Abstract: Recycling of wastewater is important for achieving sustainable use of water in both urban and rural areas. Currently, in Australia, there are strict regulations on disposal and reuse of wastewater. Irrigation of sporting fields is one of the most common applications of wastewater recycling. However, there is an increased risk of soil salinity in the vadose zone when recycled water is used for irrigation. This is due to the generally increased levels of salt in the recycled water compared to that of town water supply. This paper presents salt transport modelling for a sporting oval (Greygums Oval) in Western Sydney which has been irrigated with recycled water for more than four years. The modelling was carried out for 1277 days using HYDRUS 1D, which is a one dimensional salt transport model. Meteorological data was used to specify atmospheric boundary conditions, which was collected from nearest weather station of Penrith Lakes, 4 km from the Greygums Oval. Average total dissolved solids (TDS) of recycled water varied in the range of 480-630 mg/L. Hydraulic loading rate and salt loading of applied irrigation water were 160 mm/year and 713 kg/ha/year, respectively.

The results of salt transport modelling of recycled water for irrigation showed a 77% increase (from 0.38 g/L to 0.67 g/L) in the root zone soil water TDS concentration over the period of 1277 days. However, during the simulation period, predicted TDS concentration showed significant fluctuations, which can be attributed to the influence of rainfall on soil water content and the movement of salt within the rootzone. The increasing trend was supported by a limited number of field data points. The field data collected generally supported the findings of the model. However, more field data are required to validate the model.

The results also indicate that weather conditions, particularly rainfall, appear to have significant impact on the accumulation of salt in the soil. That is, accumulation of salt in the soil due to recycled water applications can be more critical in the arid than in the tropical rainforest climatic conditions. For arid regions, due to limited availability of water, there is an increased pressure for using recycled water for irrigation. The results of this study appear to indicate that, if the recycled water is applied indiscriminately, the soils in this region may be under severe risk of salinization. However, further studies are required to quantify the risk of salinisation.

Keywords: *Salt transport modelling, Urban irrigation, Vadose zone*

Prediction of trihalomethanes in drinking water

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Abstract: Chlorine disinfection of potable water is commonly practised in Australia, particularly where distribution systems have relatively short hydraulic retention times. Water treatment plant operators chlorinate with the aim of being able to maintain a residual disinfectant throughout the distribution system. Dissolved natural organic matter (DOM) can react with chlorine thereby reducing the chlorine concentration. A consequence of the reaction of chlorine with DOM is the formation of disinfection by products of human health concern, such as trihalomethanes (THMs), haloacetic acids (HAAs) and haloacetonitriles (HANs).

We report a model developed for prediction of total trihalomethanes (TTHMs) and the four constituent compounds. This model comprises a series of algorithms each designed to describe the impacts of various factors (chlorine consumption, bromide concentration, temperature and pH) on total THM and specie abundances.

Data were obtained from controlled experiments using surface waters as collected and after treatment or spiked with bromide, at temperatures ranging from 4^{o}C to 35^{o}C and controlled pH (6.5 to 9). THM species were determined using an automated headspace sampler (Perkin Elmer, TurboMatrix 110) followed by gas-chromatography with electron-capture detection (Perkin Elmer Clarus® 500 GC).

Data were transformed to percentages based on a standardized test condition (the formation of TTHM at 0.1 mg L^{-1} Br, pH 7, temperature 15^{o}C assigned 100% formation) and from this the % THM formations for other test conditions were assigned.

Mathematical relationships were established between the relative abundances of the four species, as percentages, with the ratio of the concentrations of Br to Cl_2 reacted. Models were determined by application of the software TableCurve™ (Hearne Software Pty Ltd.). Data acquired indicated linear relationships between TTHM and pH from 6.5 to 9 and between TTHM and temperature. The relationship found between bromide concentration (to 0.5 mg/L) and TTHM was approximately linear, with a slight decline at the higher bromide level. Rates of formation depended on the decay of chlorine, with relatively higher rates at lower chlorine decay levels. Data from five water sources from the UK (raw and partially treated {post GAC}), and several Australian waters, from Victoria and South Australia (Happy Valley Reservoir conventionally treated surface water (CTSW) blended with RO waters sourced from seawater, SWRO) were used for model development. These varied markedly in their chlorine demands and subsequent THM formation, with rates of formation ranging from about 30 to 60 µg TTHM/mg of chlorine consumed. Average percentages of model fitted to actual TTHM data were as follows: (1) 88% for UK raw waters, (2) 103% for UK GAC treated waters, (3) 108% for unblended conventionally treated surface water, (4) 101% for 75:25 CTSW-SWRO blend, (5) 113% for 50:50 CTSW-SWRO blend and (6) 109% for 25:75 CTSW-SWRO blend. Based on this model and settings applied, the data indicates overall under-prediction for some water types and over prediction for others, with an overall average of 103.6% to actual data. Prediction of chlorinated and brominated species was based on the initial concentration of bromide to chlorine consumed and has been previously reported.

The model aims to be versatile in application through capacity to readily modify the influence of bromide on TTHM formation and on the formation of the four chlorine-bromine THM species. Findings to date indicate the existence of influencing factors on TTHM and species still to be identified. Model calibration is needed for specific potable waters, based on source and treatment applied.

Keywords: *THM, disinfection, chlorine*

Simulation of shallow strata deformation caused by groundwater drainage in Shanghai

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Abstract: Land subsidence in Shanghai has been severe since 1921, which is caused by excessively pumping ground water. The total area of land subsidence comes to 5,000 km^2 with the maximum cumulative land subsidence of 2.67 m. Measures of artificial recharge and reduction of pumpage have been effectively taken since around 2000 to control land subsidence. Ground water levels in four confined aquifers rise obviously. The average rises in water levels in the confined aquifers 2 and 3 are 0.5m/yr, and those in the confined aquifers 4 and 5 are 3.0m/yr. At the same time, the average decrease in land subsidence rate is 5mm/yr and some areas even begin to rebound. There are almost no pumping wells in phreatic aquifer and first confined aquifer because of bad water quality. Ground water levels and deformation in shallow strata, which refers to all the sedimentary layers above the second confined aquifer, do not show similar change. The deformation of shallow strata accounts for more than 90% of the total land subsidence since 2000, and the deformation rate does not decrease although groundwater levels are increasing in the confined aquifers from second to fifth. For example, the cumulative land subsidence at extensometer F21 is 67.0mm from 2006 to 2011, and the shallow strata compacts 60.9mm during the period which accounts for 90.8% of the total subsidence. There are two reasons of continuous compaction in shallow strata along with ground water levels increase in deep confined aquifers. One is that pore water pressures in the aquitards response much later than those neighboring aquifers. The other one is large-scale underground engineering with significant ground water extraction. Groundwater levels in shallow aquifers decrease obviously, at the same time deformation occurred in the construction layer and overlying soft soil layers. It brings severe uneven land subsidence and negative effect on the safe operation of major infrastructure.

Shallow strata deformation in 2011 in central area of Shanghai, which covers 2649km, is simulated in this study to show the mechanism of the two causes mentioned above. The land subsidence model built in this study includes a three-dimensional ground water flow model with a one-dimensional (vertical) subsidence model using finite element method. The aquifer systems include all the sedimentary layers above third confined aquifer with averaged thickness of 120m. The study area is discretized into a series of prism elements and is divided into 10 layers vertically. Each layer is discretized into 3381 nodes and 6490 elements. Finite element method is applied to solve the numerical model. The whole aquifer system has 219 parameters zones. Field data of groundwater levels and deformation are used to calibrate and verify the model by trial-and-error method to adjust parameters, until the results of ground water levels and deformation fit the observations well. The simulation results show that, the compaction deformation positively correlated with the thickness of soft soil layers with same change in groundwater levels. In ancient river cutting area, amount of deformation is large because of thick soft soil layer. Deformation is small in the area with hard clay layer and thin soft soil layers. The changes of shallow ground water levels have a significant impact on the safety of subway in downtown area, which is constructed on thick soft soil layers. Deformation of shallow strata in the central area of Shanghai after ten years is predicted by the land subsidence model.

Keywords: *land subsidence, numerical model, ground water pumpage, shallow stata, Shanghai*

Numerical modeling land subsidence arrested by artificial recharge and reduction of pumpage in Shanghai

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Abstract: The city of Shanghai in China suffered severe land subsidence due to excessive withdrawal of groundwater over the past 90 years. The maximum cumulative land subsidence is 2.67 m where the averaged elevation of the city is between 2.2 m and 4.8 m, and the total area of land subsidence approaches 5,000 km^2. Shanghai government has been trying to take two methods of artificial recharge and reduction of pumpage to control land subsidence since 1960s, especially during the recent years.

The aquifer system in Shanghai consists of six aquifers, including one unconfined aquifer, the first to the fifth confined aquifer. The total amount of artificial recharge in the aquifer system increased from 15.65 million m^3 in 2006 to 18.61 million m^3 in 2011, and the total amount of pumpage decreased from 57.04 million m^3 in 2006 to 13.50 million m^3 in 2011. Groundwater levels are rising fast in most area of Shanghai. The water levels in the confined aquifers 2 and 3 rise 2-3 m in the city centre, and those of the confined aquifers 4 and 5 rise 15-20 m. As a result of this rising, the land subsidence rate decreased. Observations from 24 extensometer groups showed that the mean amount of cumulative land subsidence was 17.9 mm from 2006 to 2011. However, cumulative compaction of the strata above the second confined aquifer was 18.6 mm. This revealed that the strata from second confined aquifer to the fifth confined aquifer expand of 0.7 mm. The measures of artificial recharge and reduction of pumpage in Shanghai are indeed achieving the purpose of alleviating land subsidence.

Land subsidence in Shanghai from 2006 to 2011 is simulated in this study to show the results of the two control measures taken here. The land subsidence model built in this study includes a three-dimensional ground water flow model with variable parameters and a one-dimensional (vertical) subsidence model using finite element method. The nonlinearity of governing equations can be handled by solving the equations in an iterative way. The system was discretized into a series of prism elements and is vertically divided into 12 layers with an average thickness of about 25 m, which means each layer contains one aquifer or one aquitard. Each layer is discretized into 8,317 nodes and 16,204 elements. Finite element method is applied to solve the numerical model. Hydraulic conductivity, specific storage, and the coefficient of compressibility of the soil are considered as variable parameters along with land subsidence. The parameters to be determined include initial void ratio, the preconsolidation stress, compression index, swelling index, initial hydraulic conductivity. Each layer is divided into several parameter zones based on the topography, geology, and soil types. The whole aquifer system has 333 zones with different parameter values. Field data of groundwater levels and deformation were used to calibrate and verify the model by trial-and-error procedure.

The results show that the proposed land subsidence model developed in this study can appropriately simulate the expansion of sedimentary layers below the second confined aquifer. However, there are larger errors between calculated and observed data in the sedimentary layers above second confined aquifer. One reason may be that the deformation of the sedimentary layers above second confined aquifer is influenced by the impacts of massive construction of high buildings, subways or railroads, which is presently neglected in the model. Impacts of construction of high buildings, subways or railroads on land subsidence should be properly evaluated in further study.

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Keywords: *land subsidence, numerical model, artificial recharge,* reduction of pumpage, Shanghai

Modeling the deformation of faulted volcano-sedimentary sequences associated to groundwater withdrawal in the Querétaro Valley, Mexico

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Abstract: The City of Querétaro is located on a graben structure that formed a continental basin filled since the Oligocene time with volcanic and sedimentary materials. In the N-W direction two major normal faults are dipping to the West and the thicknesses of the filling materials vary many tens of meters in close distances. The filling materials include lacustrine and alluvial sediments, pyroclastic deposits, and interbedded fractured basalts. Hence, important differences of hydraulic and mechanical properties characterize the various units.

Groundwater was been strongly withdrawn over the last three decades in the study area, with a level decline exceeding than 100 m in some areas. Because of the high variability of the geological deposits, a space variable decrease of the piezometric levels, and consequently of the effective stress increase, has been observed. Piezometric variations are also due to faults that strongly impact on groundwater flow dynamics. The variable distribution of the effective stress increase has caused large differential subsidence causing ground fracturing that has damaged the urban infrastructures of the City of Querétaro.

The geological heterogeneities of the subsoil were integrated into a flow and geomechanical model to predict the deformation caused by fluid withdrawal. Initially the hydrodynamics of the pumped aquifer system was simulated by a 3-D groundwater flow model and then the subsidence was computed with the aid of a 3-D poro-mechanical model with the pore pressure field specified as an external distributed source of strength within the porous medium. The model is calibrated using observed groundwater and land settlement records, with the generated three-dimensional stress field that is compared with the distribution of the major fractures detected in the city.

The aim of this work is to predict the differential deformation of the faulted volcano-sedimentary sequences. The simulation is carried out by an advanced three-dimensional finite-element flowdynamic-geomechanical code. The conceptual model was accurately defined using the correlation of geological logs of extraction wells, field mapping of faults, fractures, and the integration of major structures reported in previous geophysical works. The stratigraphic sequences were simplified with seven mayor hydrogeological units with specific mechanical properties, hydraulic conductivity, and storage capacity. The 30 years records of piezometric level were used to simulate groundwater depletion and the resulting land subsidence.

The results of the geomechanical simulations show that the areas where large differential subsidence developed correspond to the portions of the city where earth fissuring have been observed. The spatial relationship between major withdrawals and the largest simulated subsidence is assessed.

Keywords: *Groundwater withdrawals, land subsidence, earth fissuring, modeling, Querétaro (Mexico)*

Application of the Multiscale Finite Element Method to the numerical modeling of regional land subsidence

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Abstract: For a regional land subsidence problem, there are difficulties for the traditional finite element method to solve the regional groundwater flow equation involved. A new finite element method - multiscale finite element method (MsFEM) applied to resolve three dimensional groundwater flow problem- is introduced. Three advantages make the MsFEM very useful for groundwater flow simulation in a large region with highly heterogeneous porous media. One advantage is that this method can significantly save computing efforts by coarse grid mesh. The variation of parameters in an element is brought to the multiscale base functions. Second one is that this method can to a large extent avoid large aspect ratios of elements by combining aquifers and aquitards in one element. The third advantage is that the hydraulic heads in different depths of aquitards or aquifers could be rather accurately interpolated using the multiscale base functions and the nodal heads of the element by MsFEM. The third advantage is useful for the subsidence modeling. A numerical example is done to verify the advantages of MsFEM. Finally, the MsFEM is applied to solve the regional land subsidence model of Shanghai, which includes a three-dimensional groundwater flow mathematical model and a one-dimensional subsidence model. The traditional two-step approach is followed in this study, with the hydrodynamics of the pumped multiaquifer system first simulated by a 3-D groundwater flow model and the subsidence then computed with a 1-D subsidence model with the pore pressure field specified as an external distributed source of strength within the porous medium. The simulation period is from March, 1986 to December, 1998. Using MsFEM, the aquifer system in Shanghai is divided into six layers, which means one aquifer and one aquitard are in one layer with an average thickness of about 50 meters. Every element in MsFEM is subdivided into 7 sub-layers in the vertical direction and every horizontal layer in an element is divided into 4 hexahedral elements. So each element is subdivided into 28 hexahedral sub-cells, which allows the heterogeneity of aquifers and aquitards to be considered by multiscale base functions. The aquifers system in total is discretized into 19,996 elements with a total of 25,000 nodes. The hydraulic heads in any depth of aquitards or aquifers could be interpolated using the multiscale base functions and the nodal heads of the element. It is very useful for the settlement calculation for the aquitards or aquifers after hydraulic heads at nodes of elements are obtained by MsFEM. The application of MsFEM significantly saves computing efforts, effectively decreases the aspect ratios of elements and obtains good results, which proves the MsFEM can be applied to solve the real regional 3D groundwater flow problems, and it is an effective numerical method for regional land subsidence modeling.

Keywords: *Multiscale finite element method, Numerical modeling, Regional Land subsidence*

The Potential Mechanisms of Yinguoan Earth Fissure using 3D Seismic Exploration Data

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Abstract: Earth fissures with unexpected emergence occur in different regions of the world, especially in Su-Xi-Chang area, Jiangsu Province, China. In this area, earth fissure features attributed to human activities such as excessive groundwater withdrawal and coupled with distinctive geological structures are widely developed, and Yinguoan earth fissure is a recognized example around this area. Here, the high-resolution 3D seismic exploration technology is proposed for Yinguoan earth fissure formation. The 3D seismic exploration data provide interpreters with the ability to map structures and stratigraphic features (such as viscoelastic strata, buried bedrock hill and aquifer thickness variation) in 3D detail. Furthermore, the correlation between the earth fissure and the above three intrinsic factors are semi-quantitatively analyzed. The results demonstrate the potential of the 3D seismic exploration for investigating sites where earth fissures exist and offer a prerequisite to physical and numerical modeling for predicting sensitive area of earth fissure.

Keywords: *Earth fissure; 3D seismic data; visco-elastic strata; buried bedrock hill; aquifer thickness variation; Yinguoan, Wuxi City*

Simulated impact of urban expansion on future temperature heatwaves in Sydney

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Abstract: The combined effect of climate change and urbanisation on 2-m temperature are investigated over Greater Sydney using the Weather Research and Forecasting (WRF) model. The climate of the region is simulated at 2km horizontal spatial resolution for the present (1990-2009) and a possible future (2040-2059) climate scenario (following the A2 emission scenario). The model default land use is replaced with a more accurate dataset that covers the Sydney area, which also includes the expected urban expansion in the future simulation according to local government urbanisation plans. The areas with projected land use changes are identified and compared with the rest of the region to evaluate how urban expansion and global warming will act together on the persistence of warm conditions.

Larger heat capacity of urban structures and inhibited evaporation by impervious surfaces are responsible for changes in the surface energy flux partition, which in turn affect near-surface temperature. In addition to changes driven by climate change alone, future urbanisation will greatly affect minimum temperature, and thus nighttime heatwaves. The urbanisation footprint on minimum temperatures is noticeable throughout the year but it is particularly strong during winter and spring, when the differences with the surroundings are especially marked. Daytime heatwaves are also projected to increase over Greater Sydney, with larger changes over the interior, but urban expansion has no perceptible impact on the occurrence of maximum temperature heatwaves, which suggests that the changes are caused by climate change alone.

Seasonal differences for each of the temperature daily extremes, as well as between maximum and minimum temperature, are partly explained by the prevalent direction of winds that compensate or intensify the effect urbanisation on local temperatures.

Keywords: *Regional climate, climate models, temperature, urbanisation*

Initial NARCliM Evaluation

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Abstract: NARCliM (NSW/ACT Regional Climate Modelling project) is a regional climate modeling project for the Australian area. It will provide a comprehensive dynamically downscaled climate dataset for the CORDEX-AustralAsia region at 50km, and South-East Australia at a resolution of 10km. NARCliM data will be used by the NSW and ACT governments to design their climate change adaptation plans.

NARCliM uses WRFv3.3 regional climate model (RCM) to perform an ensemble of simulations for the present and the projected future climate. WRF is run in three different model configurations (different combinations of physical parametrizations) that have been shown to perform well in the South-East Australia and were chosen based on performance and independence. These three RCMs are simulating three different periods: 1990-2009, 2020-2040 and 2060-2080. Four different GCMs (MIROC-medres 3.2, ECHAM5, CGCM 3.1 and CSIRO mk3.0) from CMIP3 will be used as initial and boundary conditions for the WRF simulations. These GCMs were chosen through a process that considered model performance, independence and projected future changes. Thus an ENSEMBLE of 12 simulations for each period will be obtained. Additionally to the GCM-driven simulations, 3 control run simulations driven by the NCEP/NCAR reanalysis for the entire period of 1950-2009 are also performed in order to validate the RCMs performance in the area. In this talk, we will present the initial evaluation results of the long control period simulations of the project. This includes an analysis of the models ability to capture the influence of large scale oceanic modes on the regional climate.

Keywords: *Regional climate, Australia, model, WRF*

EXTENDED ABSTRACT ONLY

Insights from downscaling for southern Australian climate projections

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Abstract: Dynamical and statistical downscaling of global climate model (GCM) outputs has the potential to reveal regional detail in the projected climate change signal. It can do this mainly through producing outputs with higher resolution with more information about local influences such as topography and coastlines. Also, biases in the host model can be reduced through the process of downscaling, either through an explicit bias correction or statistical normalization of the GCM inputs. Higher resolution and correction of biases can provide valuable insights when making regional climate projections. However, confidence in such insights first require understanding of what input data is used from the host model, what biases are reduced and what new biases are potentially introduced. One further requires understanding of its climate change signal and how it differs from that of the host model. It is then useful to understand what is driving the regional change pattern revealed by the downscaling, and attribute the effects of both finer resolution and bias adjustment. Special note should be made of any effects introduced by the particular approach and configuration of the downscaling method.

Here we examine projected changes to mean rainfall in southern Australia in the cooler seasons (autumn through to spring) by comparing outputs from five host GCMs from the CMIP3 archive and downscaling of these five models using two different methods. The two methods are the dynamical Cubic Conformal Atmospheric Model (CCAM) that includes bias correction of its inputs, and the analogue-based Bureau of Meteorology statistical downscaling model (SDM). Regional projections typically show a reduction in rainfall across much of southern Australia in winter, primarily due to an expansion of the tropics and southerly movement of the westerly storm tracks. However, there is regional variation in the magnitude of drying amongst the GCMs, and some regions that go against the general projected change. Also, GCMs have non-trivial biases in the simulation of circulation in the region in the current climate.

There are some differences in the climate change signal between the host models and the two downscaling outputs. The difference in the Bureau SDM to the host model can be related to two factors; (a) finer resolution of influences such as topography and (b) the choice of predictors and their normalization. The difference in CCAM to the host GCM can be related to three slightly different factors: (a) finer resolution, (b) bias correction of sea surface temperature inputs and (c) the configuration of the atmospheric model. The bias correction and different configuration of CCAM manifest mainly through a different bias in the current climate and a different response to warming patterns of land and ocean in a warming climate. Some aspects of the change signal in the two downscaling outputs appear to be robust regional detail related to finer resolution, but others present an alternative but not necessarily more plausible projection. This presents a challenge for making projections for the region that incorporate the projections by GCMs as well as the insights from downscaling.

Keywords: *Downscaling; Climate models; Rainfall projections;*

High resolution rainfall projections for the Greater Sydney Region

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Abstract: Projected changes in the future rainfall of the Sydney metropolitan region were investigated through fine scale (2km grid) dynamical downscaling from a single global climate model (GCM) simulation using the Weather Research and Forecasting (WRF) regional climate model. Projections of rainfall (2040-2059) were compared with a reanalysis-driven simulation for the period 1990-2009. There are projected to be changes in rainfall throughout the region with substantial temporal and spatial variation.

The primary mechanisms for these changes were investigated using daily and monthly model outputs. Increased autumn rainfall is primarily caused by greater frequency and intensity of heavy rainfall events during some years. The increased intensity of these rainfall events may be due to greater availability of moisture from the tropics and the interaction between tropical and sub-tropical systems. The influence of the local topography on rainfall patterns is also evident at this scale. However the seasonal variation of change in rainfall is mainly determined by the outer domain and boundary conditions.

Keywords: *Weather Research and Forecasting (WRF), rainfall projection, downscaling*

Using large-scale diagnostic quantities to investigate change in frequency of East Coast Low events

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Abstract: The Eastern Seaboard of Australia (ESB) is a different climatological entity to the rest of eastern Australia. Major climate drivers such as the EL Nino – Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) have substantially weaker correlations with rainfall in this region than elsewhere in eastern Australia. Recent research suggested that east coast lower (ECL) is the dominant driver of climate, which strongly influenced extreme rainfall along the ESB. ECLs are intense low-pressure systems which occur on average several times each year off the eastern coast of Australia, in particular, southern Queensland, New South Wales (NSW), and eastern Victoria. ECLs often intensify rapidly overnight making them one of the most dangerous weather systems to affect and damage the eastern coast of Australia each year. They are also a major source of water for the reservoirs serving coastal communities since ECL events were identified as being responsible for most of the high inflow in the NSW coastal catchments.

In this study, two large-scale diagnostic quantities, Isentropic Potential Vorticity (IPV) and geostrophic vorticity (GV), were taken as indicators of ECLs, which were calculated using outputs of historical and future WRF simulations from the NSW/ACT Regional Climate Modelling (NARCliM) project. NARCliM uses regional climate model WRF to perform an ensemble of simulations for the present and the projected future climate. WRF was run in three different physics combinations (R1, R2 and R3) that have been shown to perform well in the South-East Australia and were chosen based on performance and independence. These three RCMs were used to simulate three time periods (1990-2009, 2020-2040 and 2060-2080). Four selected GCMs (MIROC-medres 3.2, ECHAM5, CGCM 3.1 and CSIRO mk3.0) from CMIP3 are used as initial and boundary conditions for the WRF simulations. Outputs from six simulations (MIROC and ECHAM5 driven) are available by now and used in this study.

The monthly thresholds for IPV/GV were quantified for matching the indicated monthly ECLs to subjectively analysed monthly ECLs for the first time period (1990-2010). The same monthly thresholds were applied on the other two future time periods to get the monthly distribution of indicated ECLs. The diagnostic results for the future period were compared with those for the historical period to identify the change in frequency and seasonal shift in distribution.

All six simulations showed the same trend of decrease in frequency for IPV indicated ECLs. Only five in six simulations showed the same trend for GV indicated ECLs. The mean magnitude of decrease in frequency was smaller for MIROC driven simulations than ECHAM5 driven simulations, R3 simulation than other two (R1 and R2) simulations. Changes in monthly distribution showed that the decreases in frequency were mostly in cold season, and increases in frequency were dominantly in winter season, especially for the period of 2060-2080. This suggests that the total number of ECLs is likely to decrease in the future and there can be a shift in monthly distribution from cold season to warm season for future ECL events.

Keywords: *Regional climate model, vorticity, east coast low*

Ensemble bias and variance corrected high-resolution downscaled climate projections for Southeast Asia

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Abstract: Due to its complex topography and diverse climate (e.g. monsoonal rainfall, tropical cyclones), Vietnam is expected to be greatly affected by climate change. Therefore, detailed information about possible changes is crucial for the planning of climate adaptation measures. The most recent climate projections generated by coupled global climate models (GCMs) as well as earth system models (ESMs) for the CMIP5 experiment are still too coarse to provide this information. Using the conformal-cubic atmospheric model (CCAM), a stretched-grid atmospheric model, regional climate projections with approximately 10 km horizontal resolution over Vietnam have been produced. The downscaling method involves two steps. First, a global 50 km even-grid run is conducted driven just by bias and variance corrected monthly sea surface temperatures and sea ice concentrations from six different CMIP5 GCMs/ESMs and two RCP emission scenarios (RCP4.5 and RCP8.5). In the second step of the downscaling method, a 10 km stretched-grid version of CCAM is forced by spectrally filtered results from the 50 km global simulations.

Validation of the 50 km and the 10 km simulations of the present climate will be presented. The climate projections from the GCMs, 50 km and 10 km simulations will also be discussed to show some of the impact of the downscaling method and resolution on the projections for Southeast Asia and Vietnam.

Keywords: *Climate change, regional climate, dynamical downscaling, Vietnam*

EXTENDED ABSTRACT ONLY

Dynamically downscaled simulations of tropical cyclones: A multi-model approach for the south-west Pacific

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Abstract: The dramatic and damaging effects of tropical cyclones (TCs) are already clearly apparent in the current climate, making potential changes in the frequency or intensity of these storms in the future of immense interest. Projected changes in tropical cyclones under future climate scenarios is therefore an important and extensively studied area of recent research. The changes in tropical cyclones are found to be highly model dependent but globally, a decrease in the number of TCs is projected. This decrease is most pronounced in the southern hemisphere basins which have not been as extensively studied as northern hemisphere basins. Although studies have shown a projected decrease in the number of TCs, changes in the intensity of these systems is also likely.

The present study concentrates on the south-west Pacific where many island nations are strongly affected by tropical cyclones through loss of life and damage to crops and infrastructure due to heavy rainfall, strong winds and storm surges associated with TCs. Data from the latest generation of global climate models produced for phase 5 of the Coupled Model Intercomparison Project (CMIP5) is used to analyse changes in TCs including numbers, locations, intensity and duration between the historical and Representative Concentration Pathway 8.5 (RCP8.5) scenario experiments by the end of the 21st Century. Although GCMs are relatively coarse they are able to simulate TC-like features. Using a detection algorithm allows us to detect these TC-like vortices directly from the climate model data. Three CMIP5 models were chosen based on their ability to simulate the climatology of large-scale fields important for TC genesis and development as well as the simulation of TC-like vortices in the current climate. There is found to be a decrease in the numbers of tropical cyclone-like vortices detected in the GCM data under future climate conditions.

Since the GCMs are relatively coarse and unable to properly resolve TCs, they are unable to reproduce the observed intensities. In order to analyse changes in intensities, the individual events detected in the GCMs were downscaled using moveable grid versions of the Weather and Research Forecasting (WRF) and Regional Atmospheric Modelling System (RAMS) models with multiple nesting down to a resolution of 4 km. The use of two different limited area models provides an idea of the robustness of any changes. The ability of these limited area models to simulate the TCs in the current climate is assessed and changes in wind speed, pressure, size and rainfall under the future climate scenario are examined. Preliminary results show an increase in the size and intensity of TCs occurring in the future. These will have likely knock-on effects on waves, storm surge and coastal erosion.

Keywords: *Tropical cyclones, climate change, downscaling*

Consistent Climate Scenarios: projecting representative future daily climate from global climate models based on historical climate data

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Abstract: As part of the Commonwealth Department of Agriculture, Fisheries and Forestry's (DAFF's) 'Australia's Farming Futures Climate Change Research Program' (CCRP), the Queensland Government undertook a project to support the climate data requirements for nine climate adaptation studies. The project, known as Consistent Climate Scenarios (CCS), delivered climate change projections data, in consistent model-ready formats, enabling project teams to undertake climate change adaptation studies for various primary industries across Australia, in particular within the grazing, cropping and horticultural sectors. Statistical approaches were developed to transform historical climate data from the Queensland Government's SILO climate database using climate projections modelling from the Intergovernmental Panel on Climate Change (IPCC), Fourth Assessment Report (AR4). All IPCC AR4 models from the Third Climate Model Intercomparison Project (CMIP3) were ranked by an Expert Panel overseeing the CCS project. Ranking was based on model performance over the Australian region using, as a guide, methods developed by Suppiah, et al. (2007) and Smith & Chandler (2010). Of 23 available models, four were omitted as underperforming, and the remaining models were used to develop the CCS projections data. Over 1 million data files were delivered to the CCRP project teams. These projections data are now available to the wider research community as an adjunct to SILO. Registered users can obtain 'CCS data' at http://longpaddock.qld.gov.au/climateprojections.

Two different techniques are used to modify the daily observed climate values extracted from the SILO database (http://longpaddock.qld.gov.au/silo) using trends obtained from global climate models (GCMs). The two techniques are monthly change factors (CF) derived by pattern scaling from GCMs, and quantile matching (QM). The CF technique projects trends in mean values whereas the QM technique projects both the mean and internal variability within climate sequences. The initial CF trend data were obtained from CSIRO and constituted the monthly trends interpolated to 25 km grids by OzClim ™ (http://www.csiro.au/ozclim). This set included trends in maximum and minimum temperatures for only seven required GCMs, and did not include specific humidity for five GCMs, or solar radiation for two. Estimation techniques, using the combination of machine learning and regression techniques (Ricketts&Carter 2011) were used to estimate missing variables. The UK Met-Office has also made available maximum and minimum temperature, and specific humidity files for the HadCM3 and HadGEM1 models, which had not been available to CSIRO from the IPCC's repository at PCMDI (http://www-pcmdi.llnl.gov/). The QM methodology (Li, Sheffield & Wood 2010, Kokic, Jin & Crimp 2012, Kokic, Jin & Crimp 2013) was developed in conjunction with CSIRO. Two variations of QM are described in these papers, one which requires daily data from the GCM (which is only available from a very small subset of GCMs) and one which uses monthly GCM data.

Data generated by the methods described may be downloaded after registration, currently at no additional cost from the web site. Users may request up to ten datasets at a time, selected from SILO's 4759 available patched point stations, projected to either 2030 or 2050, based on six SRES scenarios and two stabilization scenarios, and three different climate sensitivities. They receive projection files in a choice of two formats, plus additional data (e.g. CO_2 concentrations, diagnostic plots and a comprehensive user guide). In addition to the nine CCRP projects, more than 120,000 files have been downloaded from this web site in the 2012/13 financial year to eight Australian universities and a number of state bodies and consultancies.

Keywords: *climate change projections, SILO, consistent climate scenarios (CCS), pattern scaling, quantile matching*

Regional climate change projections for the Tully sugar region

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Abstract: Faced with the challenges of a changing climate, it is imperative that primary industry decision makers have access to climate projections on a local scale. In the Australian sugar industry, changes in maximum and minimum temperature, radiation and rainfall can significantly affect future economic and environmental sustainability. In northern regions an increase in rainfall during the harvest season can lead to crop standover and lower economic returns. Modelling the effects of climate change at a local scale will help develop regional management strategies.

General Circulation Models (GCMs) allow researchers to explore projections of climate variables under a range of possible future emission scenarios. However, current outputs from GCMs are often only available at a coarse resolution (up to 300 km by 300 km). As a result many small scale conditions that can affect climate variables are often not represented in GCM outputs. Sugarcane in Australia is primarily grown in a narrow band on the eastern coast. The Tully region of northern Queensland is situated between the World Heritage Listed Wet Tropics Rainforest and Great Barrier Reef. Topographical changes across the Tully sugarcane-growing region result in climatology varying spatially. Downscaled GCMs can provide a bridge between large scale climate projections and the need for local climate variables. This paper explores climate change projections for maximum and minimum temperature, radiation and rainfall in the Tully sugarcane-growing region at a high spatial resolution.

Temperature and rainfall data were obtained from 11 GCMs for the period 1961 to 2000. Projections for this period were based on 20th century forcings (20C3M) as described by the International Panel of Climate Change (IPCC). GCM projections for the period 2046 to 2065 were also obtained, based on a high emissions scenario (A2). A statistical downscaling methodology was used to downscale daily temperature and rainfall data on a 0.05 by 0.05 decimal degree grid (approximately 5 km by 5 km). Data were downscaled for grid locations known to grow sugarcane within the Tully region. Daily radiation data were not available using the downscaling process. Instead, daily radiation data were generated from downscaled rainfall and temperature data. Equations for daily radiation were parameterised using temperature and rainfall data from a nearby high quality weather station and calculated total solar flux. Estimates were bias corrected to replicate weather station records of radiation.

The projected change in each of the four climate variables was assessed on a regional level for the 11 GCMs and spatial variations within the region were identified. For temperature and radiation variables, the absolute projected change was calculated. For rainfall the projected *relative* change was calculated. The relative change was defined as the percent change from the baseline period (1961 to 2000). Projected changes were analysed at each grid point for summer, autumn, winter and spring. The regional mean change was calculated for each GCM and a 95% bootstrapped confidence interval was produced for the 25th, 50th and 75th percentiles of the paired differences. The percentiles of projected change across the range of GCMs were used to capture the uncertainty between model projections. If the 95% confidence interval of the 50th and 75th (25th) percentile captured only positive (negative) values, an increase (decrease) was considered plausible. An increase (decrease) was considered highly plausible if the confidence intervals for the 25th 50th and 75th all captured positive (negative) values.

For the Tully region, an increase in temperature was considered highly plausible for all seasons under A2 simulated forcings. A projected decrease in radiation was considered highly plausible for winter and spring and plausible for autumn. A relative increase in radiation was plausible for summer and a relative increase in rainfall was considered plausible for spring. However, projected changes in seasonal rainfall varied spatially within the Tully region. An increase in seasonal temperature and rainfall may require changes to traditional management strategies. High resolution climate change projections can help industry decision makers develop localised, robust adaptation strategies. Local adaptations are vital for an economically and environmentally sustainable future.

Keywords: *Temperature, radiation, rainfall, GCM, downscale*

Comparison of future runoff projections using different downscaling methods

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Abstract: Global warming leads to changes in future rainfall and runoff that has significant impact on the regional hydrology and water availability. All the large-scale climate impact studies use the future climate projections from global climate models (GCMs) to estimate the impact on future water availability. Downscaling techniques are commonly used in modelling climate impact on hydrology studies to transform the lower resolution climate model outputs to a finer scale suitable for regional or catchment scale impact assessment. There are a number of downscaling approaches reported in literature ranging from simple to complex. Many impact studies rely on an empirical scaling method (also referred to as 'change factors (CFs)', 'perturbation method' or 'delta-change method' in various studies) that scales the historical record based on GCM outputs. More complex methods include statistical downscaling that establish relationships between large scale predictors and local scale predictands and computationally intensive dynamical downscaling that embeds a higher resolution regional climate model (RCM) within a GCM.

In light of the diversity of the available downscaling approaches, this study aimed to explore the merits and limitations of different downscaling methods in modelling climate change impact on runoff. To do so, we first assessed the historical daily runoff and salient runoff characteristics modelled using rainfall from three widely used downscaling methods – Analogue, NHMM, and WRF – and compared them with the modelled runoff using observed rainfall. We then compared the future runoff projections (change in future runoff) derived from these downscaling methods. The modelling experiments were carried out for eight unregulated catchments in south-eastern Australia. The downscaling models were driven by NCEP/NCAR reanalysis data (NNR) and one GCM (CSIRO mk3.5). Two hydrological models – GR4J and Sacramento –were calibrated against observed streamflow data and used to model historical and future runoff. The SILO Data Drill was used for validation.

The statistical downscaling methods (Analogue and NHMM) performed well in reproducing historical rainfall and runoff characteristics when driven by NNR. But this was not necessarily the case when they were driven by historical GCM simulations. The performance of the dynamical downscaling method (WRF) was sensitive to the spatial resolution it was applied and similar amount of biases are observed when driven by both NNR and GCM. The systematic biases in the downscaled rainfall highlight the need for applying a bias correction method. However, our experiments showed that a simple linear bias correction method need to be used with caution as it can adjust the rainfall distribution in a wrong way which lead to larger biases in runoff. Furthermore, the benefit of the linear bias correction method on future runoff projections is unclear as it does not seem to have major impact on change in runoff characteristics. The results indicate that there can be substantial differences between the future runoff projections from different downscaling methods. The differences for mean annual runoff between the different downscaling methods are usually smaller compared to those for other salient runoff characteristics.

Keywords: *Runoff projection, downscaling, climate change, analogue, NHMM, WRF*

Evaluation of Downscaled POAMA M24 for Monthly and 3-Monthly Streamflow Forecasts

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Abstract: This paper evaluates skill of ensemble forecasts of monthly and three-monthly streamflows for three catchments from different hydrological regions, using a conceptual hydrological model - the GR4J. The latest available POAMA-M24 rainfall predictions for the period of 1980-2008 are downscaled and used as forcing inputs of the model to produce streamflow forecasts. In dealing with model uncertainty, 200 parameter sets derived through BATEA are used for each downscaled rainfall forcing. The results show that skill scores are both catchment and season dependent. In the Biggara catchment (SMD region), Jan., Apr., and Nov. are the months with the highest skill scores; for the Picnic Crossing catchment (QLD region), the best forecasts are for June and July, while for the Tinderry catchment (SEC region), the best forecast months are Sept. to Nov. and Feb. as well. The skill scores of monthly steramflow forecasts are higher than that of three-monthly forecasts except for reliability. Slight difference between M24-E33 and M24-E99 is found when additional forcings with lead times of 1 and 2 months are used in the ensemble forecasting.

Keywords: *streamflow forecasts, ensemble forecasts, GR4J, POAMA*

Bayesian hierarchical modelling of rainfall extremes

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Abstract: Understanding weather and climate extremes is important for assessing, and adapting to, the potential impacts of climate change. The design of hydraulic structures such as dams, drainage and sewers, for instance, relies in part on accurate information regarding patterns of extreme rainfall occurring at various locations and at different durations. Deriving this kind of information is challenging from a statistical viewpoint because a lot of information must be extracted from very little data.

In this paper, we describe the use of a spatial Bayesian hierarchical model (BHM) for characterising rainfall extremes over a region of interest, using historical records of precipitation data from a network of rainfall stations. The rainfall extremes are assumed to have a generalised extreme value (GEV) distribution, with the shape, scale and location parameters representing the underlying variables of the BHM's process layer. These parameters are modelled as a linear regression over spatial covariates (latitude and longitude) with additive spatially-correlated random process. This spatial process leads to more precise estimates of rainfall extremes at gauged locations, and also allows the inference of parameters at ungauged locations. Furthermore, it also mitigates the limitations imposed by short rainfall records in that it allows the model to "borrow strength" from neighbouring sites, thereby reducing the uncertainty at both gauged and ungauged locations. Making use of *r*-largest order statistics in the data layer further allows the integration of multiple yearly rainfall amounts instead of the annual maximum only.

The proposed BHM uses a parametric representation that links the GEV scale parameter obtained for different accumulation durations. This approach leads to two additional process parameters, and allows the use of pluviometer data accumulated over a range of durations, thereby also increasing the amount of data available for inference. A main advantage of the Bayesian approach is that measures of variability arise naturally from the framework. These uncertainty measures represent information of crucial importance for a subsequent use of the estimated quantities.

We demonstrate this Bayesian approach using a dataset of pluviometer measurements recorded at 252 meteorological stations located on the Central Coast of New South Wales, Australia. For each station, the rainfall data is accumulated over 12 different durations ranging from 5 minutes to 72 hours, from which the two largest annual maxima are selected. Exploratory analyses of this rainfall dataset are carried out for various purposes, including: (*i*) basic quality control (removal of erroneous data values), and (*ii*) to provide insight into the relevance of the model structure and associated assumptions.

The proposed model is fitted using Markov chain Monte Carlo (MCMC) simulation, with several types of diagnostics plots used to assess the convergence properties of the resulting chains. We present numerical examples of estimated parameters resulting from the fitted model (regression coefficients, sill and range of the spatial correlation function) together with confidence intervals. Further results from this study are provided by calculating intensity–duration–frequency (IDF) curves for a few sites of interest (both gauged and ungauged) with associated estimates of uncertainty. These results are shown to be in good agreement with station-based maximum likelihood estimates, while achieving smoother curves with tighter uncertainty bands.

Keywords: *Pluviometer data, spatial statistical modelling, generalised extreme value distribution, Markov chain Monte Carlo, intensity–duration–frequency curve.*

Modeling the Effects of *Sewer Mining* on Odour and Corrosion in Sewer Systems

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Abstract: Increasing demand has led to shortage of potable water in many countries. The use of alternative water sources is one of the solutions undertaken to overcome this issue. Alternative water sources can be derived from either collected rainwater, treated greywater or treated wastewater. *Sewer Mining* is known as an efficient technology which can reduce the cost of wastewater infrastructure required to transport wastewater because the *Sewer Mining* facility is usually installed close to the site that is using the treated wastewater. The treated water from *Sewer Mining* has been used as one of the sources of alternative water, particularly to supply water for public open spaces, garden irrigation and toilet flushing. It is conducted by extracting the sewage from sewer pipes and most of the times, disposing the sludge back to sewer pipes. The sewage extraction and sludge disposal back to sewer network is suspected to trigger sewer problems such as blockages. Several applications of *Sewer Mining* facility have proved to contribute to the increase of blockages in sewer pipes. Furthermore, the changes in the sewage composition after the sewage extraction and sludge disposal location lead to alteration of the sewage biochemical transformation processes, which finally were suspected to change the state of hydrogen sulphide build up. Increase of hydrogen sulphide in sewage and in the sewer atmosphere could also contribute to the problem of odour and corrosion in sewers.

This study attempts to model the impact of *Sewer Mining* on odour and corrosion in sewer systems. A residential area in northern Melbourne was used as a study area. In this study, four *Sewer Mining* scenarios were considered, consisting of Base Case (BC), Sewer Mining 1 (SM1), Sewer Mining 2 (SM2) and Sewer Mining 3 (SM3). The scenarios were configured based on the volume of sewage extraction. *Base Case* is the scenario representing the existing condition of water and wastewater use in the study area and there was no *Sewer Mining* facility in the area. Sewer Mining 1, 2 and 3 represent the scenarios when the *Sewer Mining* is undertaken and the sewage extraction was adjusted to supply 25%, 50% and 70% of the households in the study area. The location of sewage extraction and sludge disposal was fixed at the middle of main sewer pipe network and was not changed for each scenario. The treated water from the *Sewer Mining* facility was supplied as water for toilet flushing.

Two modeling tools were used for this analysis, the first was an urban wastewater generation model and the second was a sewage transformation (and generation of hydrogen sulphide) model. The output of the first model, namely wastewater flow discharge and contaminant concentration were fed to the second modeling tool. Wastewater generation from the households was simulated in the first modeling tool while *Sewer Mining* practice was modeled in the second modeling tool. Its impact was analyzed in the sewer pipes downstream of the *Sewer Mining* facility. The analysis results were obtained by comparing the result from *Sewer Mining* scenarios 1, 2 and 3 with the *Base Case*. The difference in total sewer flow, hydrogen sulphide gas production, corrosion rate and the pipe lifetime were the analysis parameters that are discussed in this paper.

The results showed that *Sewer Mining* led to reduction in hydrogen sulphide concentration immediately after the sewage extraction point, but further downstream, the hydrogen sulphide concentration was extremely high. The hydrogen sulphide concentration at the outlet of sewer pipes network for SM1, SM2 and SM3 scenarios had increased up to three, five and eight times respectively, when compared to the hydrogen sulphide concentration in the *Base Case*. Increase of hydrogen sulphide concentration consequently lead to increase in odour occurrence and corrosion rate which eventually reduce the sewer pipe lifetime. The pipe lifetime at the outlet of sewer network reduced by 204 years, 262 years and 293 years after implementing the scenarios of SM1, SM2 and SM3, respectively. The distance where the extremely high hydrogen sulphide generation occurred was very much determined by the volume of extracted sewage and the location of extracted sewage and sludge disposal.

Keywords: *Sewer Mining, Sewer systems, Odour, Corrosion, Hydrogen Sulphide*

Implementing Future Climate Change Scenarios Using a Stormwater Drainage Model for an Urban Catchment in Melbourne

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Abstract: One of the most important infrastructure in an urban area is its stormwater drainage system, which is used to convey the excess rainfall from the surface of the urban catchment to the natural watercourse. Conventionally, these structures are required to perform properly under the selected and generated events known as *Design Rainfalls* which have been statistically calculated using the recorded rainfall from the past. These events include the intensity and duration for the design rainfalls with different return periods or frequencies and are assumed to demonstrate the pattern and frequency of the previous rainfall events. This stationary assumption is currently questioned due to climate change. It is expected that high intensity rainfall events would be more severe and frequent. This in turn would lead to frequent flash floods as the urban stormwater drainage system would not be able to cope with the increased intensity of the storm events.

In Australia, the maintenance of the urban stormwater drainage system is the responsibility of local councils. With increase in rainfall intensities due to climate change, it is essential to assess the capability of existing drainage systems in handling these extreme events. With this aim, this research attempts to implement future scenarios of climate change for an urban catchment in Melbourne using a hydraulic model. The initial step in developing the hydraulic model included the extraction and correction of drainage system data from the GIS data available with the local council. The hydraulic model was calibrated and validated using captured flow data from the catchment.

Different scenarios for future climate change were developed and a scenario representing the future change is applied to the model and the results are presented in this paper. The results are expected to assess the capability of the drainage system to cope with the future climate change. The future scenario used design rainfalls of 6 hrs duration and return periods of 50 and 100 years, which were extracted from the IFD curves obtained from the Bureau of Meteorology web site. These design rainfalls were increased by factors of 10%, 20% and 30% and the impacts of these increased rainfall events on the drainage system were assessed. The impacts were especially addressed using three important functional parameters of the drainage system under each scenario. These parameters were:

- Infiltration loss
- Surface runoff
- Final surface storage (Depression Storage)

It was observed that for the analysis using 6hrs duration design rainfall, a 30 percent increase in the rainfall intensity, for 50 years return period events, the maximum runoff change is 44.5% while the infiltration loss and final storage increased by 9.6% and 7% respectively. For the 100 years return period and increase in rainfall by 30%, the three factors (of infiltration loss, surface runoff and final surface storage) increase by about 8.7%, 42.8% and 7.2% respectively. It is observed that the increase in the surface runoff is considerably higher than the increase in infiltration and storage capacity. Any further increase in the extreme events would contribute in more surface runoff accumulation.

Keywords: *Hydraulic model, climate change, urban drainage systems, extreme rainfall events*

Modelling Impact of Extreme Rainfall on Sanitary Sewer System by Predicting Rainfall Derived Infiltration/Inflow

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Abstract: Extreme climate events are becoming more intense in Melbourne in recent years. This increasing intensity of excessive rainfall has an adverse effect on the sewer network by causing sewage overflow hazards. Extreme rainfall events increase flow into the sewer system, both directly (inflow) and through infiltration into sewer. As a result of this Rainfall Derived Infiltration and Inflow (RDII), Sanitary Sewer Overflows (SSOs) may occur. These SSOs carry inherent risks to human health as well as lead to environmental pollution.

This paper demonstrates a rigorous and efficient procedure of predicting RDII in a sewer system in Melbourne, Australia by using the Sanitary Sewer Overflow Analysis and Planning (SSOAP) toolbox. The SSOAP toolbox is a new freely available tool designed by the U.S. Environmental Protection Agency (EPA) for modeling of RDII. In the SSOAP toolbox, the U.S. EPA Storm Water Management Model (SWMM5) is incorporated for the hydraulic routing of the sanitary sewer system. For RDII flow estimation, SSOAP implements the synthetic unit hydrograph (SUH) method. In the literature, this procedure is recommended as the most accurate and industry standard methodology of determining RDII. The simplest SUH contains three triangular hydrographs to describe the fast, medium, and slow RDII responses. Each hydrograph has total of three parameters named R,T,K. R is the fraction of rainfall volume entering the sewer system as RDII during and immediately after the rainfall event, T is the time to peak, and K is the ratio of the time of recession to T. This method is known as the RTK unit hydrograph curve-fitting analysis.

In the SSOAP toolbox, the three main input data used for RDII prediction are flow, rainfall and sewershed data. The SSOAP toolbox analyses rainfall and flow data and identifies dry weather flow (DWF) and wet weather flow (WWF) periods. RDII flow components for storm events are defined by hydrograph decomposition of measured flow data. The tool estimates R, T, K parameters for each rainfall/flow monitoring event and generates RDII hydrographs.

This paper provides an in-depth description of RDII analysis using the SSOAP toolbox for a case study catchment in Glenroy suburb It is located within the larger Pascoe Vale catchment in northern Melbourne. It is a residential area. The main reason for choosing this particular area as the case study is that the sanitary sewer pipes are quite old; therefore, the problem of SSOs are common. Three flow meters were used for flow data collection and rainfall data were obtained from the Bureau of Meteorology for a nearby rain gauge station. As the downstream flow meter location is the most critical point (as it receives wastewater flow from the whole catchment), the paper focuses on flow data from the downstream flow meter location for the RDII analysis. Two storm events have been analyzed for calibration of the RDII unit hydrograph parameters (namely, the R,T,K parameters).

This paper presents a simple calibration procedure of RTK parameters. The SSOAP toolbox provides automated calibration using a visual approach. The main purpose of this automatic visual calibration is that the simulated RDII flows closely match the RDII time series generated by decomposing the measured flow data. The SSOAP toolbox is shown to be a useful software for RDII analysis, as the simple, interactive and visual approach facilitates easy determination of the R,T,K parameters, rather than use of the complicated numerical techniques used in the past. Moreover, this study demonstrates the accuracy of the generation of R,T,K parameters using this software. As part of future research, these R,T,K parameters or the RDII hydrographs will act as input to a sewer simulation model like SWMM5 for the hydraulic analysis of existing sewer system. This would help in identifying locations which are at risk or prone to SSOs.

Keywords: *Extreme Rainfall, Sanitary Sewer Overflows (SSOs), RDII, SSOAP Software.*

Changes in Intensity-Frequency-Duration Relationship of Heavy Rainfalls at a Station in Melbourne

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Abstract: A primary concern in the context of climate change impacts is related to the increase in the intensity and frequency of heavy rainfall events. The risk of heavy rainfall events (i.e. floods and drought) has increased over the world, and the intensity and frequency of heavy rainfall events are very likely to increase in the future with the exception of the regions with very significant decreases in rainfall.

More intense and frequent heavy rainfalls due to climate change and variability are a major concern for urban and rural flooding that causes damage to hydraulic structures such as dams, roads and stormwater drainage systems. Potential impacts of climate change on heavy rainfalls question the accuracy of current design rainfalls, which are used in estimating the hydraulic capacity of these structures. If there is a significant trend in heavy rainfall events, currently used design rainfalls obtained through Intensity-Frequency-Duration relationship may cause hydraulic failures and flood damages in case of underestimation. On the other hand, it would be a waste of money in the event of overestimation of design rainfalls.

In this study, first heavy rainfall trends for daily and sub-daily storm durations were investigated. Rainfall data from the Melbourne Regional Office station over the period of 1880-2010 were used for trend analysis of heavy rainfalls. The non-parametric rank based Mann-Kendal and Spearman's Rho tests were selected for trend analysis in this study due to distribution free characteristic of these tests. The Mann-Kendal and Spearman's Rho tests were applied to detect trends in annual maximum rainfall intensities of the selected storm durations (i.e. 6, 12, 18 and 30 minute, and 1, 2, 3, 6, 12, 24, 48 and 72 hour). The trend tests showed statistically significant increasing trends for sub-hourly storm durations (6, 12, 18 and 30 minute). Also, the data sets of 1, 2 and 3 hour storm durations indicated increasing trends, but not significant even at 0.1 significance level. On the other hand, 6, 12, 24, 48, and 72 hour heavy rainfall data sets showed statistically insignificant decreasing trends.

Then, the changing character of rainfall Intensity-Frequency-Duration (IFD) relationships were quantified through the analysis of four time slices (i.e. 1880-1909, 1910-1949, 1950-1979 and 1980-2010) using rainfall data from the Melbourne Regional Office station in Melbourne. The results of the frequency analysis of heavy rainfalls for 4 time slices showed that the IFD relationships vary over the period 1880-2010. Remarkable increases in sub-hourly design rainfall intensities were detected for the time slice 1980-2010. However, there is no evidence to state that increases in design rainfall intensities are statistically significant.

This study aims to demonstrate a methodology for the investigation of heavy rainfall trends and IFD relationship using rainfall data from a single station in Melbourne. Therefore, it is not realistic to extrapolate the findings of this study without further analysis using data of the many stations.

Keywords: *Climate change, rainfall intensity-frequency-duration relationship, generalized extreme value, annual maximum series*

Dynamical Seasonal Prediction of Climate Extremes in the Pacific

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Abstract: The vulnerability of Pacific Island Countries to climate extremes is exacerbated by a changing climate. Many of the early impacts of climate change are being felt through seasonal variability. Drought and coastal inundation are two examples of events which occur as seasonal variability but are made more severe by increased mean temperatures and rising sea levels. Early warnings of extreme climate events from dynamical coupled ocean-atmosphere global climate models (CGCMs) can increase resilience by providing a lead time in which action can be taken.

Dynamical seasonal forecasting systems are now competitive with the best statistical forecasting techniques, with the advantage that they implicitly include the effects of a changing climate, reducing concerns about the effects of climate change and decadal variability on forecasts. Dynamical models have the advantage of providing information at a range of timescales from weeks to seasons and for a range of physical quantities including extreme ocean temperatures, tropical cyclone activity and sea level.

We have developed dynamical model based seasonal forecasts for Pacific Island Countries, including monthly to seasonal forecasts of extreme sea levels, extreme ocean temperatures and tropical cyclone activity. These new forecasts of extreme climate events work in concert with more traditional seasonal outlooks for rainfall, temperature and climate indices to provide rich foresight of near-future climate variability.

Outlooks are delivered via interactive web-based geospatial apps, providing broad scale and local information about climate risk to National Meteorological Services in 15 partner countries. Investing development time in open-source geospatial data infrastructure and re-usable user interface frameworks has enabled rapid development of new tools for forecasts of new predictands. Extension of prediction research to the responsible agencies has involved training of users and continuing support.

Keywords: *Seasonal prediction, Climate extremes, Dynamical climate model*

Observed hydrologic non-stationarity in south-eastern Australia and implications for modelling predictions

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Abstract: The term 'hydrologic non-stationarity' has been used to describe many things, ranging from different climate-runoff relationships evident in different periods within a long hydroclimate time series to changes in hydroclimate characteristics and dominant hydrological processes in an increasingly warmer and higher CO_2 world. This paper presents different aspects of hydrologic non-stationarity in south-eastern Australia exposed by the 1997–2009 Millennium Drought and discusses the implications for future modelling predictions. The examples come from extensive analyses and modelling using a large climate and hydrological data set from across south-eastern Australia.

The very large decline in the 1997–2009 runoff (48% reduction averaged across far south-eastern Australia) is caused not only by the decline in mean annual rainfall (13% reduction), but also by the lack of high rainfall years (compared to previous long droughts where there are above average rainfall years within the drought period), proportionally higher reduction in cool season rainfall when most of the runoff in this region occurs and higher potential evaporation associated with higher temperature. The decline in cool season rainfall has been partly attributed to changes in atmospheric circulation in a warmer world (in particular the expansion of the Hadley cell pushing cool season mid-latitude storm tracks further south), and is consistent with climate model projections of a drier future in far southern Australia. Annual rainfall-runoff models cannot capture processes at sub-annual and inter-annual time scales, and empirical annual models calibrated against pre-1997 data significantly overestimate the 1997–2009 runoff. The predictive skills of daily conceptual hydrological models are also limited when there are significant changes in the climate-runoff relationship, with the hydrological models calibrated against pre-1997 data also poorly simulating and overestimating the post-2007 catchment runoffs.

The Millennium drought also exposed hydrologic processes that become more dominant in long dry spells. The paper shows, through analyses of and modelling with rainfall, streamflow and groundwater data sets, that reduced connectivity between surface and subsurface water and farm dams intercepting proportionally more water during dry periods, can accentuate the runoff decline from the lower rainfall. The moderate-rainfall low-relief catchments are likely to be most impacted by the reduced connectivity between surface and subsurface water, where falling groundwater levels increase the storage capacity of the unsaturated zone resulting in less organised connection of the source runoff areas. High-rainfall and high-relief catchments are less affected because the formation of saturation areas is predominantly controlled by the high rainfall, while the generally lower groundwater levels in low-rainfall catchments are unlikely to play a major role under any condition.

Nevertheless, as the Millennium drought has highlighted the importance of these hydrologic processes. Now that we have seen the changes in the climate-runoff relationship, we can adapt hydrological models to better simulate these processes and calibrate models against long historical records that also include the extreme conditions of the Millennium drought. These models should be sufficiently adequate to predict changes in the near-term runoff which is driven mainly by the rainfall inputs. It is considerably more difficult to predict changes further into the future, which will be increasingly influenced by complex interactions and feedbacks between many variables and processes (particularly vegetation behavior) in a considerably warmer and higher CO_2 world.

Keywords: *Hydrologic non-stationarity, south-eastern Australia, Millennium drought, climate-runoff relationship, hydrological prediction, Millennium drought*

Simulating the combined effects of climate and wildfire on streamflow

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Abstract: In February of 2009, after prolonged periods of hot and dry weather, wildfires spread across part of the state of Victoria, affecting more than 363 km2 of forests in the Melbourne water supply catchments. This has potential to alter long term water use (>100 years) of the forests and subsequent water yield from these catchments. Climate can have an important role in modifying the effects of fire on streamflow. One of the few ways to examine these is through a process-based modelling study. It is important that the combined effects of climate and wildfire on long term streamflow are included in simulations used by water managers for planning and decision making.

We used a spatially explicit process-based model to explore relationships between climate and wildfire, and examine the combined influence of climate and wildfire on the post-fire streamflow response. Catchments were disaggregated into spatial units at which energy and water balances are simulated. Changes in land cover were expressed as changes in leaf area index (LAI) for the fire sensitive ash-type eucalypt species, and for the more fire-tolerant mixed eucalypt species forests.

Catchment water balances were simulated for 100 years after wildfire to include most of the expected changes. We assumed post-fire mortality of vegetation from recent field studies, along with several climate scenarios to examine the response of post-fire catchment streamflow. Effects of climate variability were removed by creating a synthetic climate, with no inter-annual variability, and using this as an input to model.

Under wetter than average conditions, change in post-fire water yield was largely explained by changes in average age of the forest, where ET is largely determined by the conductance and interception of the forest canopy. Under drier conditions, evapotranspiration is largely under the control of soil water content, and so differences in vegetation cover and canopy conductance across catchments are likely to have less effect on evaporative fluxes and consequently on streamflow. Under lower than average rainfall conditions, when water becomes limiting, annual rainfall was the best predictor of post-fire change in water yield. This can result in little or no statistically significant change in post-fire streamflow, even when large areas of a catchment are affected by fire (Bart and Hope, 2010).

Under conditions of low rainfall and low soil water content that are conducive to larger wildfires, any initial increase in post-fire streamflow due to reduced canopy cover may not occur or be detected because a substantial soil water deficit must first be removed before appreciable changes in streamflow will occur. We conclude, therefore, that the likelihood of detecting changes in streamflow after severe wildfire is lower when rainfall is low.

Keywords: *process-based modelling, Macaque, forest, wildfire, streamflow*

EXTENDED ABSTRACT ONLY

The use of multi-duration relationships for deriving design rainfall estimates in Australia

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Abstract: Intensity-Frequency-Duration (IFD) design rainfalls are generally derived by fitting an extreme value probability distribution to either an Annual Maximum Series (AMS) or Partial Duration Series (PDS) of point rainfall data. To overcome uncertainties due to short record lengths and spatial sampling, regionalisation approaches are often used to fit the extreme value distribution. A common regionalisation approach assumes that the probability distribution in a local neighbourhood is the same at all stations, aside from a site specific scaling factor. This regionalisation is applied to each rainfall duration separately. Because of this, the rainfall quantile estimates at the same location for different durations are not related. In some locations this can lead to inconsistent estimates of rainfall depths from different durations (such that the rainfall depth from a shorter duration is larger than the depth at a longer duration).

A number of scaling relationships have been proposed in the literature to investigate the relationship between different time scales but to date these have not been considered for practical application for Australia. In general a scaling exponent can allow the IFD curves to be estimated with more precision or is used to extend the IFD relationships to ungauged locations. In this paper the relationship between the scaling exponent and the moments of the AMS data have been considered. A number of different methods were considered to calculate the moments of the AMS data including Probability Weighted Moments (PWM), L-moments and Non-central Moments (NCM). It was found that there are clear scaling relationships for the first three moments when using PWMs and NCMs and the first L-moment (i.e. the mean). However this relationship was not found for the higher order L-moments. This has implications for common regionalisation methods that are based on combining index flood approaches with L-moments.

It was also found that the relationship between the moments of the data and the rainfall duration generally follows two simple scaling relationships, with a common slope for durations from 1 minute to around 15-30 minutes and a separate relationship evident for durations from 30 minutes to 7 days as shown for a sample location in Figure 1a. There are some interesting spatial variations in the scaling exponents as shown in Figure 1b, which presents the slope of the fitted linear regression of log of the first PWM on log duration. The implications and potential added value of these scaling relationships to regionalisation procedures need to be considered.

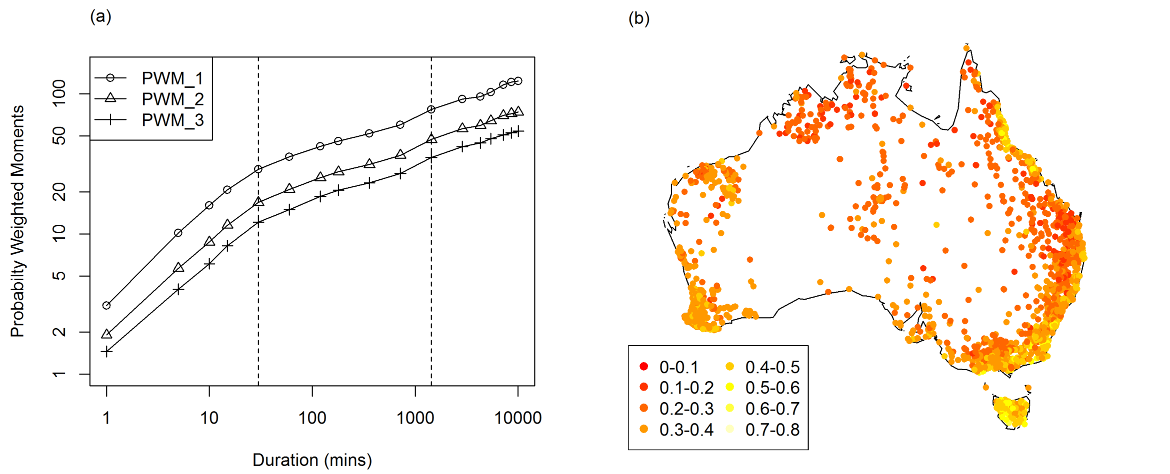

Figure 1a. Example scaling relationship between event duration and first three Probability Weighted Moments, **b.** Spatial variation of scaling exponent across Australia fitted to durations from 60 minutes to 12 hours.

Keywords: *Extreme rainfall, scaling, IFD*

Estimating the contribution of rainfall and evapotranspiration changes on future flood risk

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Abstract: One of the major questions that is currently concerning planning agencies and infrastructure owners is whether future flood risks will increase or decrease due to anthropogenic climate change. Although there is some observational evidence for increases in extreme rainfalls, particularly for sub-daily durations, the situation is far from clear when all the drivers of flood risk are considered together. Firstly considering only rainfall, situations that may lead to uncertain changes to flooding include catchments where overall decreases in rainfall lead to drier catchments and hence smaller flood flows despite increases in extreme rainfall intensity and/or frequency. On the other hand, changes in the seasonality of flood producing rains may likewise decrease flood risk if the timing means that the catchments are drier, or conversely increase the flood risk if the antecedent moisture prior to the flooding rains is higher. It is not clear *a priori* for any individual catchment which of these changes is likely to dominate the future flood behavior. Furthermore, coupled with these rainfall changes are the possible changes in evaporation, sea level and storm surge which will also impact flood risk. The combination of all flood drivers becomes a problem in the field of compound extremes and requires new multivariate methods and frameworks to accurately define the changes in flood risks.

This study investigates the contribution of rainfall and potential evapotranspiration (PET) to overall flood risk. Eight representative catchments in south-west and south-eastern Australia were chosen as shown in Figure 1 and a TOPKAPI model was established for each catchment. The catchments were chosen to cover a range of climatic conditions and catchment properties, in particular catchment size and mean runoff coefficient.

The current climate sequences of rainfall and PET were generated using the Stochastic Climate Library maintaining the correlations between temperature, PET and rainfall. The daily rainfall sequences were disaggregated to provide hourly rainfall data as an input to the TOPKAPI model. The climate sequences were then modified to change the rainfall and PET properties in a number of ways to explore potential interactions and their impact on the peak flow in the 5% Annual Exceedance Probability (AEP) event. By considering eight different catchments, the study is able to consider whether these changes can be related to catchment or climatic characteristics.

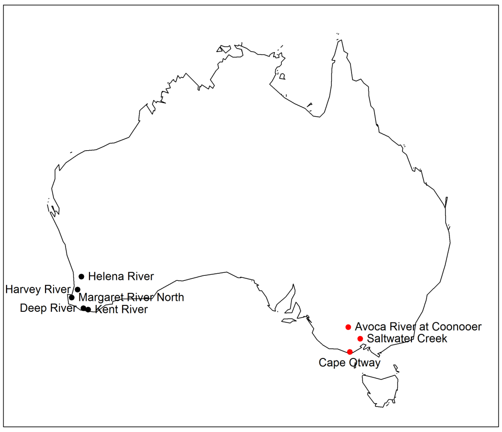

Figure 1. Locations of eight catchments used to capture the relative importance of different flood drivers compared to catchment characteristics

Keywords: *Extreme rainfall, flooding, climate change, compound extremes*

Seasonal sea-level predictions for the Western Pacific

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Abstract: Seasonal forecasting from dynamical ocean-atmosphere models of sea-level anomalies (SLA) has great potential for coastal communities in the Western Pacific, allowing the implementation of management policies and strategies to minimise loss of life and infrastructure damage. In recognising that it is through natural variability that the early effects of climate change are most acutely felt, the Pacific-Australia Climate Change Science Adaptation Planning Program (PACCSAP) seeks to assess the relationships between the seasonal variability, regional sea-level and its predictability at a seasonal timescale.

Real-time forecasts for SLA in the Western Pacific are currently produced operationally using the Bureau of Meteorology's seasonal forecast model POAMA. This work represents the first attempt to predict seasonal SLA up to 7 months into the future using a coupled dynamical model. These forecasts provide an early warning of potential extreme sea-level, which allows coastal managers to both minimise coastal damage and ensure water security, as well as brief stakeholders. Additionally, probabilistic forecasts provide information as to the likelihood of an extreme seasonal mean state, which is very useful for management in planning responses and focusing resources.

An online portal has been created to deliver the seasonal forecasts and accompanying skill scores. Website development was done in consultation with regional stakeholders with the aim to produce useful and easily understood seasonal forecasts. These forecasts are a new product for regional stakeholders and the assessment of the forecast usefulness and application is an ongoing task. As global warming is likely to increase the frequency and severity of extreme SLA events the development of such forecast products is crucial to combat problems due to climate change in the near future.

Keywords: *Sea-level, dynamic modeling, Pacific-Australia Climate Change Science Adaptation Planning Program (PACCSAP), seasonal forecasting, POAMA*

Drought related changes in rainfall-runoff relationships and its impact on model performance

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Abstract: A basic rule of conceptual rainfall-runoff modeling is that calibration data should be representative of the conditions in which the model is used. However, by definition, climate change studies deal with non-stationary hydrological time series where projected future conditions may be outside the range of historical observations. Thus, even a long-term historic record with a number of dry and wet cycles might not be representative for projecting climate change impacts on water yield. Previous studies have recognised that some model parameters depend on the climate of the calibration period and validation accuracy declines as the difference between calibration and validation rainfall increases. Prolonged droughts in Australia, including the recent Millennium drought (circa 1997-2010), provide an opportunity to explore this issue as climate projections suggest a drier climate in South East and South West Australia and some other regions around the world.

To partially test model performance under a sustained rainfall deficit, six conceptual rainfall-runoff models were calibrated in multiple catchments using a combined daily Nash-Sutcliffe Efficiency (NSE)-bias objective. For each catchment, multiyear dry period(s) were identified in the historical records. Model calibration was performed using all available record excluding the dry period of interest. Then performance statistics for the validation dry period were calculated and analysed. In parallel, differences in rainfall-runoff relationship between the generally long calibration period and shorter validation dry period were statistically tested with a partial F-test.

Our results suggest that the rainfall anomaly of the dry period *per se* does not control either the decline in NSE or the increase in bias of the models during the validation period. However, the change in the annual rainfall-runoff relationship is found to be the important factor related to validation model performance. The NSE tends to be significantly lower when the rainfall-runoff relationship shifts down. In cases without a statistically significant change in the rainfall-runoff relationship, the model bias shifted in the positive direction in half the catchments and in the negative direction in the other half. For cases where a significant shift in the rainfall-runoff relationship is found, the bias nearly always shifts towards positive values. That is, models have a strong tendency to overestimate the flow in catchments where shifts in the rainfall-runoff relationship were detected, while performing reasonably well where such change did not occur. None of the models tested showed consistently good performance in catchments where the rainfall-runoff relationship changed during the dry period. Given that we tested a range of models with different structures and having from 4 to 18 model parameters, the issues encountered do not appear to be a structural deficiency of a particular model, but rather a general issue associated with current conceptual rainfall-runoff modeling. We hypothesise that this problem might be related to the inadequate representation of soil moisture store during drought conditions. For example, the soil may actually be drier than the models suggests, which affects both low flows (lower ground water and soil store drainage) and high flows (slower and weaker response to rainfall events).

Changes in the rainfall-runoff relationship reflect changes in hydrological processes acting in the catchment. Our results suggest that in modeling hydrological response to climate change it is important to account for not only non-stationarity in climate forcing, but also for non-stationarity in catchment processes. Understanding and predicting change in hydrological processes due to shifts in rainfall is crucial for adequate predictions in climate change studies.

Keywords: *Drought, streamflow, climate variability, rainfall-runoff modeling*

Thunderstorms in burned forests: compound extremes and hydro-geomorphic hazards

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Abstract: The increased potential for erosion, water contamination, flash floods and debris flows are hydro-geomorphic hazards that can emerge in steep forested terrain due to the combination of fire disturbance and subsequent rainfall events. Predictions of hydro-geomorphic hazards for burnt landscapes are used by land management agencies to quantify rehabilitation effectiveness, prioritize resources and evaluate tradeoffs between different land management strategies. These kinds of hazards associated with a combination of two or more events are an example of what the IPCC recently referred to as 'compound extremes'.

A key element of modelling this problem involves capturing the nature of the interaction between the forcing variables: fires and rainfall events. The frequency and size of fires is highly variable, depending on climatic conditions in a particular year. Following fire we have a "window of risk" for several years within which severe erosion events may occur, depending on whether a storm event of sufficient magnitude occurs within the burnt areas. When a storm does occur in a burnt area, the magnitude of the erosion event is dependent on the landscape vulnerability, which comprises many factors including soil properties, topography, fire severity and level of recovery. Over time, the frequency and magnitude of hydro-geomorphic hazards is a function of both the forcing variables (fire and storms) and landscape vulnerability.

Fire and erosion are frequently modelled separately. In a few cases erosion modelling efforts have been specifically targeted at burnt landscapes, though with the focus on predicting erosion rates *after* the landscape has been burnt, rather than assessing the combined impact of fire and rainfall on erosion. To the authors' knowledge, Istanbulluoglu, et al. (2004) is the only existing attempt at modelling long term fire related erosion rates which incorporates stochastic fire *and* rainfall events. In this paper we describe two new modelling approaches for this problem, one numeric and one analytic.

The first, a numerical modelling approach, involves the an annual-timestep Monte Carlo simulation that combines the probabilistic characteristics of annual fire weather and post fire rainfall events, with deterministic models for fire spread, erosion, and pollutant delivery from the burnt landscape. The new model is called a Fire Regime Impact (FRI) simulator because at the core of the model is an annual burned area generated from the Phoenix fire behaviour model, an annual realization of a long term fire regime. Water quality impacts are dependent on the coincidence in space and time of these burned areas, suitable topographic conditions, and post fire storm events of sufficient magnitude to trigger major erosion events.

The second, an analytic modelling approach, is based on the premise that the modelling focus should be directed at the magnitude of the *overlap* in time and space between burned areas and storm events, rather than at the geophysical processes that drive them individually. In this model we consider burned areas and storms as independent stochastic processes with properties of spatial extent, temporal duration, and frequency of occurrence. The volume of intersection (in time and space) of the two processes gives a measure of hazard of high-magnitude erosion events. The stochastic model is based on a germ-grain coverage process in which random sets are generated by taking a Poisson process (the germs) and then at each point centering iid random sets (the grains). The model uses two independent germ-grain processes, one for storms and the other for fires, using rate and size parameters that can be obtained from readily available fire history and rainfall data. Both models have been calibrated and applied to SE Australian fire prone landscapes.

Keywords: *Water quality, bushfire, soil erosion, stochastic processes*

Investigation of statistical methods for modelling bivariate extremes

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Abstract: Natural hazards such as floods and droughts pose a significant risk to society. These extreme events are often the result of multiple climate forcing variables, not all of which need to be in an extreme state for the impact to be extreme. Floods in coastal catchments, for example, can be caused by runoff generated by an extreme rainfall event, elevated sea levels due to an extreme storm surge event, or the combination of both processes occurring simultaneously or in close succession. Understanding joint probability between extreme variables is, therefore, critical for correctly estimating their risk.

A number of statistical methods have been developed to model the dependence between extremes, but the suitability of each method to quantify the risk of low exceedance-probability events is unclear. The study investigates three main classes of bivariate extreme value models: threshold-excess, the point process and the conditional methods. The objectives are to: (i) interpret the fitting procedures of each method in terms of modelling dependence between extreme rainfall and storm surge; (ii) better understand the suitability of each method for flood risk estimation; (iii) compare the performance of the three methods in terms of their ability to estimate low exceedance-probability events; and (iv) highlight the implications of the dependence to the flood levels using a real case study.

To achieve these objectives, we conducted a detailed numerical study, followed a case study based on observed rainfall and storm surge in the Sydney region. Based on the results of this study, we concluded:

(1) The threshold-excess method produces unbiased dependence parameters, while its application in practice is limited because it is unable to handle situations where only one of the two variables is extreme. In contrast the point process and conditional methods were able to simulate the full distribution of extremes, but led to overestimation and underestimation of the dependence strength, respectively, for the cases where the dependence was weak.
(2) The point process method overestimated the return levels, particularly when dependence is very weak, while the conditional method underestimated the return levels for various dependence values.
(3) Accounting for the dependence between extreme rainfall and extreme storm surge is critical to correctly estimate coastal flooding risk.

Based on this study, we recommend the point process method as the most suitable basis of incorporating dependence between extreme rainfall and extreme storm surge in coastal flooding risk estimation. The bias from this model is in the direction of overestimating the strength of dependence, which in most cases will lead to the more conservative estimate of total flood risk.

Keywords: *Joint probability, extremes, flood risk estimation, dependence*

Analysis of the linearised observation operator in a land surface data assimilation scheme for numerical weather prediction

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Abstract: Several Meteorological service agencies have developed Extended Kalman Filter based land data assimilation systems that, in principle, can analyse any model land variable. Such systems can make use of a wide variety of observation types, such as screen level (2 meters above the surface) observations and satellite based estimates such as retrieved surface soil moisture and retrieved skin temperature. Indirect measurements can be used and information propagated from the surface into the deeper soil layers. A key component of the system is the calculation of the Jacobians of the observation operator which describe the link between the observations and the land surface model variables. The Jacobians are estimated using finite difference by performing short model forecasts with perturbed initial conditions. This paper examines the Jacobians that link observations of screen level variables, satellite derived surface soil moisture and satellite derived skin temperature to model soil temperature and moisture.

The calculated Jacobians that link screen level variables to model soil moisture show that there is strong coupling between the screen level and the soil. The coupling between the topmost model level soil moisture and the screen level is found to be due to a number of processes including bare soil evaporation, soil thermal conductivity, soil thermal capacity as well as transpiration by plants. Therefore, there is significant coupling both during the day and at night. The sign of the Jacobians linking screen level temperature to topmost model level soil moisture are usually negative during the day and tends to be positive during the night. The coupling between the screen level and soil moisture in the deeper model layers is primarily through transpiration by plants. Therefore the coupling is only significant during the day and the vertical variation of the coupling is found to be significantly affected by the vegetation root depths. The calculated Jacobians that link screen level temperature to model soil temperature are found to be largest for the topmost model soil layer and become very small for the lower soil layers. These Jacobians are largest during the night and generally positive in value.

It is found that the Jacobians that link observations of surface soil moisture to model soil moisture are strongly affected by the soil hydraulic conductivity. Generally, for the Joint UK Land Environment Simulator (JULES) land surface model, the coupling between the surface and root zone soil moisture is weak. Finally, the Jacobians linking observations of skin temperature to model soil temperature and moisture are calculated. These Jacobians are found to have a similar spatial pattern to the Jacobians for observations of screen level temperature.

Where the linear assumption is valid, the calculated values of the Jacobians should be nearly independent of the sign of the perturbations used. This is investigated by comparing Jacobians calculated using perturbations of opposite signs. Jacobians values that are significantly affected by the sign of perturbation used are assumed to contain a gross error and not used by the data assimilation. A simple quality control scheme is developed to detect land points where the computed Jacobians contain such gross errors. Analysis is also performed of the sensitivity of the calculated Jacobians to the magnitude of the perturbations used.

Keywords: *Soil moisture, soil temperature, screen level, land surface, weather prediction*

A temporal stability analysis of the Australian SMAP mission validation site

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Abstract: The National Aeronautics and Space Administration's (NASA) Soil Moisture Active Passive (SMAP) mission is a soil moisture dedicated mission scheduled for launch in October 2014. The payload consists of a combined L-band radar and radiometer system with the objective of mapping near surface soil moisture globally. The scientific rationale for SMAP is an improved accuracy and spatial resolution of the soil moisture estimates through a unique combination of high resolution (3 km) but noisy radar derived soil moisture information and more accurate yet lower resolution (36 km) radiometer derived soil moisture information, yielding a 9 km active/passive soil moisture product.

Soil moisture estimates from remote sensing data have an inherent uncertainty due to the model required to convert the observed microwave signal into area-average soil moisture. Validation of the satellite products is thus required after launch to ensure their accuracy. This can be difficult due to the high spatio-temporal variability of soil moisture and the mismatch in scale of point measurements and satellite footprints. One method of overcoming this problem is to use hydrological monitoring networks that have been collecting data over a long period, by finding point measurement locations that are representative of the area-average values. This technique is known as temporal stability analysis.

As part of the Australian contribution to the SMAP mission, a calibration/validation site has been developed at Yanco, New South Wales. The Yanco site is part of the OzNet soil moisture monitoring network and has been intensively monitored for remote sensing purposes since 2001 (www.oznet.org.au). This paper presents a temporal stability analysis using data from the Yanco site to assess the most suitable monitoring stations to be used as the test-bed for SMAP. The soil moisture stations are located in a specifically designed nested grid to assist with the validation of the 3 km, 9 km and 36 km SMAP soil moisture products. Results show that in the cropping area, YA4 and YA7 (3 km × 3 km) are best represented by YA4b and YA7d stations, respectively. A high standard deviation in soil moisture is found in the YA (9 km × 9 km) due irrigation and cropping practices. On the other hand, the grassland area YB7 (3 km × 3 km) is well represented by the YB7d station, with the YB3 station giving a good approximation of the average soil moisture for the entire YB area (9 km × 9 km) and the Y10 station a good approximation for the entire 36 km × 36 km area.

A sensitivity analysis was then performed supporting the choice of the Y10 station and leading to the conclusion that approximately 1 year of data are required to determine the most representative station within a given area. Data from the Y10 station has been also compared to the average moisture from a number of OzNet monitoring stations and was found to provide an accurate estimate of their average value for soil moisture lower than 0.3 m^3/m^3.

Keywords: *Temporal stability, soil moisture, OzNet, Soil Moisture Active Passive (SMAP), satellite validation, monitoring network.*

Joint model state-parameter retrieval through the evolutionary data assimilation approach

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Abstract: Data assimilation (DA) methods have been widely used to improve model state estimation by merging model outputs with observations. Traditionally, studies have focused on updating model state variables but recent studies have augmented model parameters alongside model state variables to improve the estimation procedure. The updated model ensemble members represent a compromised estimation between prediction and observation. The compromise, which is usually in objective space subject to agreement between observation and model predictions, is important. However, few studies have actually employed DA procedures to investigate the updated members in decision space, through examination of the temporal changes of model states and parameters. Usually, the model states and parameters evolve/change: (i) subject to changes in observation, (ii) to account for the varied uncertainties in different land surface conditions, and (iii) due to their intricate connection with hydrologic conditions which evolve across assimilation time periods. Moreover, the update procedure in most DA methods is controlled predominantly by matchings between observation and model predictions with limited impact from decision space through model state variables and parameters. As a result, DA procedures are needed to tightly link the compromise in objective space to decision space, with the capability to examine the temporal changes of model states and parameters.

To address these challenges, this study has employed the Evolutionary Data Assimilation (EDA) method in a joint state-parameter estimation to assimilate: (i) synthetic daily soil moisture into the Joint UK Land Environment Simulator (JULES), and (ii) hourly streamflow into the Hydrologiska Byråns Vattenbalansavdelning (HBV) model. The EDA is a relatively new formulation of the multi-objective evolutionary strategy for the purpose of data assimilation. The EDA was applied to illustrate its capability to both retrieve model parameter values and to improve estimation of soil moisture and streamflow in a two-step procedure.

In the soil moisture assimilation, the first step involved the generation of initialization model state and parameter values as the original 'truth' where they were applied into the JULES model to simulate surface soil moisture, representing the synthetic soil moisture. The second step assimilated the synthetic soil moisture into a perturbed version of the JULES model to retrieve the original model state and parameter values. The updated model states and parameter values were compared to the original 'truth' to show that the EDA can both retrieve the original 'truth' parameter values and the soil moisture states. The soil moisture assimilation was illustrated for the Yanco region in New South Wales, Australia from January to December 2010.

In the streamflow assimilation, the original 'truth' values of the HBV model were obtained from two independent studies generated using: (i) the Multistart weight-adaptive recursive parameter estimation, and (ii) the Shuffled Complex Evolution. The EDA was applied to assimilate hourly streamflow into the HBV model to retrieve the calibrated model state and parameter values. The streamflow assimilation was illustrated for the Bellebeek catchment in Belgium from August 2006 to July 2007. The input data for the HBV model and data sets in the Bellebeek catchment were provided by the authors of the two independent studies.

The synthetic soil moisture were compared to the EDA updated soil moisture in the soil moisture assimilation, whereas the observation streamflow were compared to the EDA updated streamflow. The findings show a high estimation accuracy of the EDA for soil moisture and streamflow based on the evaluation measures and the two independent studies. Moreover, the updated ensemble of model states and parameter values were evaluated across the assimilation time steps showing the level of convergence for model state variables and parameters. The evaluation of the temporal evolution of updated ensemble members in decision space demonstrates the capability of the EDA to retrieve model state variables and parameters. Thus, the key potential of the EDA lies in the evaluation of updated members for model state and parameter linkages in decision space.

Keywords: *Soil moisture, Streamflow, Data assimilation, State-parameter retrieval, Evolutionary strategy.*

Improving soil water representation in the Australian Water Resources Assessment landscape model through the assimilation of remotely-sensed soil moisture products

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Abstract: Many researchers over the last decade have demonstrated how the assimilation of satellite soil moisture data can improve the accuracy of soil water representation in land surface models, and result in improved estimates of evaporative flux, drainage, and runoff. In this study we investigated whether similar benefits are achievable for the Australian Water Resources Assessment landscape (AWRA-L) model through the assimilation of AMSR-E and ASCAT soil moisture (SM) products.

The AWRA-L model was co-developed by CSIRO and Bureau of Meteorology researchers to support the Bureau's mandated reporting requirements on national water accounts and water resource assessments. AWRA-L represents the soil column as three conceptual storage layers: a top-layer (equivalent to the emitting soil layer for C- or L-band microwave radiometry); and separate layers for shallow- and deep-rooted vegetation respectively. AWRA-L was run cell-wise (i.e. no lateral flow) across the continent at 0.05-degree resolution providing estimates of daily water fluxes and stores.

We used perturbed meteorological forcing and the ensemble Kalman filter (EnKF) to assimilate AMSR-E and ASCAT SM products into AWRA-L. Evaluations to-date have been conducted using the OzNet network of *in situ* moisture sensors, but will be extended to other parts of the continent *via* the network of cosmic ray probes and (indirectly) through evaluation of independent satellite SM retrievals. Preliminary results clearly show an improvement in AWRA-L top-layer SM estimation compared to open-loop simulations. Results for the impact on root-zone soil layers are mixed, but appear to be linked to combinations of prescribed SM error and/or strength of vertical coupling between soil layers. Further investigations will identify where and when the assimilation of satellite SM benefits AWRA-L estimation in terms of soil water status and runoff estimation across Australia.

Keywords: *Data assimilation, satellite soil moisture, shallow root-zone*

Towards Land Surface Model Validation from Using Satellite Retrieved Soil Moisture

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Abstract: Land surface model validation at distributed scales is important for model improvements. Recent advances in satellite technology provide an opportunity for distributed calibration and validation of land surface models. In the past years, a number of active and passive microwave soil moisture products have become available. While passive microwave soil moisture is the preferred approach for soil moisture observation, its disadvantage is the coarse spatial resolution it affords. Moreover, many of the available satellites use sub-optimal wavelengths, and the satellite retrieval algorithms are still under development. Consequently, the accuracy of these satellite data sets needs to be verified prior to their application. However, the spatial and temporal discrepancies between in-situ monitoring and satellite footprint retrievals continue to make absolute verification of satellite retrieved soil moisture a difficult problem.

The Advanced Microwave Scanning Radiometer-2 (AMSR-2) onboard the Global Change Observation Mission 1 – Water (GCOM-W1) was launched by JAXA in May 2012. AMSR-2 is a follow on of the AMSR-Earth Observing System (AMSR-E) onboard Aqua and of the AMSR onboard the Advanced Earth Observing Satellite 2 (ADEOS-II). By combining data from AMSR, AMSR-E and AMSR-2, a 20-year record of near-continuous C-band measurements of soil moisture content is expected to be available, starting from 2001.

This study makes an inter-comparison between in-situ data from the OzNet soil moisture network (www.oznet.org.au), the AMSR-2 soil moisture product, and simulated soil moisture using JULES (Joint UK Land Environment Simulator) for the period July to December 2012. The area selected is a 60 km × 60 km study site in Yanco, NSW, Australia (34.561°S, 35.170°S, 145.826°E, 146.439°E). 10 km and 25 km soil moisture products from the descending orbit of AMSR-2, which has a repeat time of 1 to 2 days, has been used. The JULES land surface model was run at hourly time-steps and approximately 1 km (0.01°) resolution for the entire 60 km × 60 km Yanco area, which coincides with twenty-five 10 km and four 25 km AMSR-2 product grids at hourly time-steps. Due to the co-location between in-situ monitoring stations and AMSR-2 grids, comparison between both data sets was only possible at five 10 km and two 25 km AMSR-2 pixels. Where in-situ stations are available, time series of AMSR-2 soil moisture and JULES simulations were validated against in-situ measurements. AMSR-2 products and JULES simulations were also compared against each other.

The average RMSD for both 10 km and 25 km products were found to be 0.05 m^3/m^3 when compared to in-situ data, which meets the target accuracy of the mission. The AMSR-2 soil moisture was used to evaluate simulated soil moisture. Being a consistent product across time and space, AMSR-2 soil moisture can be used to identify where model simulations are inaccurate due to forcing data, parameter assignment or model physics. Whilst the opportunity in using AMSR-2 soil moisture to validate land surface models run at distributed scales was demonstrated, this study could not conclude whether the satellite or simulated soil moisture is more accurate due to possible inaccuracies in the current radiative transfer model, parameterization of soil and vegetation characteristics and prescription of precipitation data in the land surface model. The study also indicated prospects in further studies for better understanding of the Yanco site in relation to 1) representativeness of the sites used for validation and 2) effects caused by vegetation and standing water within the satellite footprint to improve the retrieval algorithm of AMSR-2 soil moisture for Australian conditions.

Keywords: *Surface soil moisture; remote sensing; scaling; land surface model; AMSR-2*

An approach to creating data-based models by formulating and simplifying over-parameterised constrained linear models

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Abstract: For water system modeling generally, it is the research subject area rather than a data set which determines which model is most suitable to be employed. The advantage of this independence between model and data is that a previously formulated physically based model can be selected which hopefully incorporates at least some of the processes of the system under study. The main disadvantage is that the model selected can be overly complex for the data set concerned. Recognising that water systems are non-linear by nature, the tendency in constructing simpler physically based models has been to equate simplicity with a small number of parameters in strongly non-linear models. An alternative approach, proposed here, is to equate simplicity with a possibly much larger number of parameters in linear models to approximate non-linear situations. Non-linear expressions can in fact be approximated to any required degree as a linear weighted combination of pre-calculated nonlinear terms. For example, the flow values of a recession curve could be approximated by fitting a weighted mixture of pre-calculated exponential expressions, where the calculation points correspond to the times when the flow had been measured. Once fitted in linear calibration, the weighted exponential parameters are thus defined and could be used to predict the recession flow at any specified time and not just recording times. Models formulated in this way transform the model calibration process to constrained multiple linear regression.

However, such models are cumbersome in that a large number of weights must be permitted for general model specification. The proposal here is to move calibration of these models away from the standard fitting-to-data approach and instead have a dual goal of the model seeking to fit data but at the same time being also subject to a user-specified force of simplification via linear programming which seeks to eliminate as many parameters as possible by forcing them to zero. At the greatest extreme of simplification all the parameters associated with the predictor variables are forced to zero and the model prediction is just a constant value. On the other hand, minimal applied force of simplification maintains a large number of redundant parameters which will cause calibration overfitting and poor performance in validation.

The essential feature of the approach is that unlike standard model calibration, the new calibration process yields a different and simpler model which is no more complex than required for the calibration data concerned. The method is quite general and is analogous in its basic form to all subsets regression. However, the incorporation of pre-calculated non-linear expressions also allows for application to a wide range of non-linear modelling situations. The requirement here is a willingness for us to reformulate our existing non-linear models into equivalent many-parameter linearly-constrained weighted linear mixtures. These reformulated models are then amenable to the calibration-simplification process in any given calibration. One issue which does arise is that the individual model parameters now have no physical meaning and indeed some parameters may be eliminated from one calibration to another. This might be viewed as a limitation by those familiar with interpreting the few parameters of nonlinear models in terms of some measure of information about physical reality. The appropriate rejoinder is with respect to the unit hydrograph. Many different nonlinear mathematical expressions and parameter combinations can be used to define a unit hydrograph. However, if well-applied to a specific calibration data set, the resulting unit hydrograph plot will look similar regardless of which mathematical expression is employed. Similarly, the information content of a linear simplified model is summarised in terms of the form of the graphical output from idealised situations, rather than by the numerical values of some fixed set of parameters. The simplification method will be illustrated in both a standard subset selection situation (selection of variables for seasonal forecasting) and in the formulation and calibration-simplification of a many-parameter rainfall-runoff model. Preliminary results suggest that a considerable degree of parameter elimination is possible without degrading model performance on validation data sets.

Keywords: *Model simplification, overfitting, calibration, linear approximation*

Can the peak discharge–total volume relationship for flow pulses be used to identify flow regime change?

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Abstract: A significant relationship between the peak discharge (Q_p) and total volume (V_T) of a flow pulse has been well established by a number of studies. This relationship can be expressed as a power law function (e.g. $Q_p = bV_T^m$, where b and m are parameters determined by calibration) and has been shown to be useful for determining the hydrologic linearity or non-linearity of catchments, identifying regional similarities between basins and estimating peak discharges. We further explore this relationship to determine whether it is most influenced by hillslope or channel storage processes and if it can be used to identify changes in catchment behaviour resulting from land-use change. The analysis uses streamflow data from ephemeral to intermittent catchments that range in scale from <1 km^2 to >10,000 km^2 and with some of these catchments being subject to well-defined, large-scale land-use change. The relationship between peak discharge and total volume of flow pulses was found to be only moderately correlated for micro-catchments (e.g. <1 km^2) and showed stronger correlations for larger catchments. Linear regression of $\log_{10}$-transformed data and the non-parametric Kolmogorov-Smirnov test were applied to the flow pulse data to identify if land use changes resulted in statistically significant differences in the characteristics of the flow pulses. The changes in these characteristics in the microcatchments were found to be generally significant but similar changes also occurred in an uncleared control catchment. In the larger catchments, differences in the linear regression coefficients between pre- and post-land clearing periods were only significant at the 95th percentile confidence interval for small flows. The Kolmogorov-Smirnov test showed that some catchments experienced 'flashier' flow pulses (i.e. higher peak discharges for a given total volume and shorter durations) following catchment clearing. The variations in response between microcatchments (<1 km^2) compared to larger catchments (>3 km^2) may reflect that the flow pulse characteristics are less sensitive to changes in hillslope land use compared to changes in the storage characteristics of the channel network in larger catchments. The analysis of the flow pulse characteristics makes use of observed data and provides an additional means of evaluating catchment responses to changes (e.g. climatic or to catchment characteristics), in addition to other commonly used analysis techniques, such as flow duration curves.

Keywords: *Land use change, linear regression, catchment scale*

EXTENDED ABSTRACT ONLY

Understanding the relationship between model parameters, objective functions and predictions for data-based modelling with conceptual rainfall-runoff models

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Abstract: Understanding the response of a model to changes in parameters is fundamental to the identification of appropriate models for prediction and decision making. Sensitivity analysis and identifiability can both provide qualitative and quantitative measures of the impact of varying parameter values and so can help select model structures, estimate parameters, and propagate and manage uncertainty.

This presentation will demonstrate the utility of a number of tools, of varying ease of use, designed for understanding general model parameter output relationship. To built intuition regarding the role of these tools, we draw on the analogy of parameter space as a map of a landscape. The parameters of a model structure describe a (high-dimensional) coordinate system, and the map can display a variety of quantities of interest, including various objective functions and predictions. As models generally have several parameters, the map cannot however be fully displayed in two-dimensions, which is why additional tools are required.

Dot plots display sampled points of the map on a Cartesian plane. 'Dotty' plots (1D projections) provide side-on views of the landscape by plotting the quantity of interest as a function of each parameter. 2D projections provide top-down views of the landscape, using a set of contour plots for each pair of parameters. These diagrams provide familiar, direct visualizations of the mapped landscape, which an analyst can use to understand some outcomes of parameter estimation and uncertainty analysis algorithms, but may not capture the full high-dimensional picture.

Sensitivity indices act like spirit levels to indicate how steep the landscape is in each direction. Local sensitivity indices report this steepness at a given location. Global sensitivity indices, such as Sobol, report the steepness across the whole landscape, for instance indicating that moving north-south crosses a mountain range, where moving east-west tends to stay at the same altitude on that range. These measures can help understand which parameters (i.e. dimensions of the landscape) optimization algorithms will be most likely to manipulate to reach the lowest or highest part of the landscape.

Response surface methods, including polynomial chaos and stochastic collocation, create a surrogate model of the mapped landscape. The surrogate model might be able to explore the landscape more computationally efficiently, and its parameters can be further interpreted. In particular, the interactions between parameters can be isolated, indicating the existence of slopes in the mapped landscape across dimensions, for instance running north-east to south-west. When estimating parameter uncertainty, an individual parameter may therefore appear to have a large range as it is possible to stay on a ridge by compensating with another parameter.

While the landscape analogy is commonly known, it is crucial to return to it to understand what each method contributes and therefore they can be used in combination to overcome their individual weaknesses. These tools are used to investigate the response of model predictions and related data-based objective functions for a conceptual rainfall-runoff model, diagnosing causes of identifiability problems and helping to improve model structure, estimated parameters and understanding of uncertainty.

Keywords: *Sensitivity analysis, identifiability analysis, response surface analysis, rainfall-runoff modelling*

Radar rainfall estimation using a dynamic Z-R relationship with parameterization conditional to measured reflectivity

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Abstract: Accurate measurement and prediction of the spatial and temporal distribution of rainfall is one of the biggest challenges in hydrology. Although rain gauges provide estimates of precipitation at fixed point locations, the network of gauges is often too sparse to represent the spatial variability of rainfall. Despite this, rain gauges are often considered as "ground truth" in formulating estimation or prediction approaches. In contrast, measurements of radar reflectivity provides information on precipitation occurring over large geographic areas, and therefore can characterize spatial patterns in rainfall. The power-law relationship, $Z = AR^b$, referred to as the Z–R relationship between reflectivity (Z) and rainfall (R) is used to convert the radar reflectivity to rainfall intensity. However, it is known that the relationship between reflectivity and rainfall intensity is different depending on whether the rainfall is convective or stratiform, and is also affected by the distribution of drop sizes. Furthermore, because rainfall gauges and individual radar pixels represent different spatial scales, a systematic bias may be introduced when the Z-R relationship is calibrated. We investigate the effects of these two issues on parameter bias in the Z-R relationship.

The Simulation Extrapolation method (SIMEX) is applied to estimate the value of the parameter "A" used in the Z-R relationship. Normally the rain gauge estimates are assumed to be error free when calibrating the Z-R relationship. Instead, SIMEX generates multiple sets of gauge rainfall with an assumed an error model. The influence of the error model is varied and the trend of error versus parameter 'A' is extrapolated back to the case of where the gauge measurements are assumed to be error free. The error model used in this research is based on two components: the first is the error in the gauge measurement itself and the second is the error introduced by the gauge not capturing the spatial variability of the rainfall within a single radar pixel (1km x 1km). The data used in this work comes from the Sydney Terrey Hills radar and the network of 150 tipping bucket rain gauge stations around the radar. Three years of radar and rain gauge rainfall are used (November 2009 to December 2011), accumulated to hourly increments.

To overcome the issue of bias in the Z-R relationship due to storm type and drop sizes, it is proposed that multiple Z-R rleationships should be used. We investigate whether the accuracy of radar rainfall estimates is improved by using multiple Z-R relationships. A wide range of gauge rainfalls was observed for each reflectivity level and the additional information available from considering these variations was used to inform the calibration of the Z-R relationship for different reflectivity ranges. The optimum number of Z-R relationships to use was also investigated. The use of multiple Z-R relationships was validated against withheld rainfall data and found to provide better estimates than a single Z-R equation.

Keywords: *Rainfall measurement, spatial variability, grid rainfall, uncertainty, error model, simex method*

Impact of time resolution on modeling performance in runoff volume and peak discharge estimation

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Abstract: Conceptual rainfall-runoff models have been experiencing many advancements in recent decades. These include improvements in model structure and wider calibration options. More complex model structure allows not only long-term modeling but also those at sub-hourly. Daily runoff volume, for instance, can be calculated at disaggregated timescales. Besides, the incorporation of sub-hourly timescales into continuous simulation models means that these models can now be used to estimate instantaneous flows. Nevertheless, the impact of time resolutions on modeling performance is not clear. Some past studies showed that the impact of timescales on model performance varied from almost no different to significant. While some studies showed higher time resolutions produced better results, the opposite has also been observed in few other studies. In relation to the calibration options, non-statistical measures have also been introduced in addition to the statistical ones.

Parafield Drain (PD) is a water harvesting and reuse scheme involved in the Waterproofing Northern Adelaide (WNA) Project. In order to develop a decision support system (DSS) for PD which includes real-time rainfall-runoff modeling, it is necessary to select the best modeling timescale in terms of model performance. The present study investigates how model performance at PD modeled by WaterCress was affected by modeling time resolutions. In particular, two modeling outputs, i.e. runoff volume and peak discharge, were subjected to the assessment. Daily runoff volume assessment was based on rainfall data at two timescales, 30-min and daily, while flood peaks were estimated at 30-min and 1-h. Parameters of the former were calibrated and validated against 20 months of historic streamflow data, while the latter compared against two historical flood peaks. In relation to the model performance assessment, WaterCress provides 4 performance measures of which three of them are statistical: coefficient of determination (R^2), Nash-Sutcliffe Efficiency (NSE) and Standard Error of Estimate (SEE); and another non-statistical measure: Percentage Volumetric Difference (VD).

In runoff modeling calibration stage, it was found that not every selected performance measures were improved. For example, VD was getting worse whenever the other measures were getting better and so forth. Assessing the model performance was therefore considered to be sufficient by considering multi-objective calibration, one from each statistical and non-statistical measures. Furthermore, a minimum of 9-month streamflow data was required to obtain calibration which was insensitive to the data length. Results also showed that higher time resolution produced slightly better prediction in runoff volume calculation and remarkably improved peak flow estimation.

Keywords: *WaterCress model, stormwater harvesting, rainfall-runoff, modeling time resolution, modeling performance.*

A comparison of statistical and conceptual models for monthly streamflow forecasting in the Lower South East, South Australia

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Abstract: A number of high value wetlands within the South East (SE) region of South Australia, including the internationally significant Coorong, are currently under threat as a result of the significantly reduced inflows they have received since European settlement. While most of the region's runoff is generated in the higher rainfall areas of the Lower SE, the naturally northerly flows have been diverted away from many of the wetlands by a series of cross-country drains that were constructed to provide flood relief by draining flood waters south-westerly to the ocean. It is now recognised that these flows should also be used to maintain wetlands in the entire SE region. Drain M, which conveys water from Bool Lagoon to the ocean near Beachport, is the largest of the cross-country drains. Recently, the ability to divert flow in a northward direction from this drain and restore the natural flow path to the Upper SE and the Coorong has been established. However, the Drain M system and its contributing catchments also contain wetlands of high importance. Thus, with the many competing demands on this water resource, it is desirable to forecast future flows at key locations along Drain M in order to maximise the outcomes achieved from the water available.

The overall aim of this study is to provide forecasts of one-month-ahead streamflow at three key locations along the Drain M system. However, declining groundwater levels in part of the region are likely to have resulted in a change in the rainfall-runoff relationship for the area and, as such, much of the available data does not represent the processes expected to be occurring currently. In this context, the accuracy and reliability of the generated streamflow forecasts are assessed. Forecast uncertainty, which is necessary for adequately representing model outputs and assessing any risks associated with water management decisions, is examined through the use of Bayesian calibration techniques to quantify parameter uncertainty. Additionally, two different hydrologic models have been used to account for model structure uncertainty: an artificial neural network (ANN) and the GR4J lumped conceptual rainfall–runoff model. While both of these modelling approaches are data-based to some extent, they are expected to have different individual advantages and limitations given the lack of representative data. While a future objective of this study will be to combine the estimated streamflow forecasts generated by the individual hydrological models such that model structure uncertainty is accounted for in a single forecast series with uncertainty bounds, the current study focuses on a comparison of the two modelling approaches and how they may be used to complement one another.

Overall, it is found that the ANN model provides more accurate forecasts at a monthly time scale, however the precision of the model is poor when applied to low flows. On the other hand, the GR4J model produces relatively wide uncertainty bounds when used for forecasting high flows, but provides accurate low-to-medium flow forecasts. The data requirements of the two models determined when each model provided better prediction performance. When the catchment was expected to have a reasonably consistent relationship between rainfall and runoff, the flexible structure of the ANN and its ability to make use of inputs other than rainfall and potential evapotranspiration (e.g. remotely sensed soil moisture) enabled this approach to provide more accurate and precise predictions. However, where this was not the case and there had been a change in the rainfall-runoff relationship, the conceptual modelling approach was found to provide reasonable forecasts using a limited but representative calibration data set, whereas such a dataset was found to be insufficient for properly calibrating and validating the ANN model. In general, both approaches provided similar forecasts, which provides greater confidence when using the outputs as one line of evidence for management decisions.

Keywords: *Rainfall-runoff, forecast uncertainty, artificial neural network, GR4J conceptual model, Bayesian estimation*

Precomputing upscaled hydraulic conductivity for complex geological structures

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Abstract: Three-dimensional (3D) geological models are built to capture the geological heterogeneity at a fine scale. However, groundwater modelers are often interested in the hydraulic conductivity (K) values at a much coarser scale to reduce the numerical burden. Upscaling is used to assign conductivity to large volumes, which necessarily causes loss of information. Recent literature has shown that the connectivity in the channelized structures is an important feature that needs to be taken into account for accurate upscaling. In this work, we study the effect of channel parameters (e.g. width, sinuosity, connectivity, etc.) on the upscaled values of the hydraulic conductivity and the associated uncertainty.

We devise a methodology that derives correspondences between a lithological description and the equivalent hydraulic conductivity at a larger scale. First of all, we deal with the conceptualization and geological heterogeneity that is typically present within the stratigraphic formation. We present a novel technique to construct three-dimensional geological models from basic hand-drawn sketches. The method is based on multiple-point geostatistics (MPS) simulations which uses training image to sample the spatial patterns expected in the subsurface. MPS requires three-dimensional training images, however, there is a limited library of analogue models presently available for use as the training image. We present a workflow starting from two-dimensional sketches drawn by a geologist. By applying rotation and affinity transformations in the facies simulation, complex nonstationary geological structures are obtained. Additional statistical characterization is obtained by transition probabilities and connectivity measures. Equivalent hydraulic conductivity is then estimated by solving a flow problem for the entire heterogeneous domain by applying steady state flow equation in horizontal and vertical directions. This is performed for many random realizations of the small scale structures to enable a probability distribution over the upscaled values to be generated. This process enables a modeler to exploit the prior knowledge of the depositional environment, and the expected geological heterogeneity, to determine likely hydraulic parameters of a large scale model.

We apply both heterogeneous and homogeneous K media to estimate the upscaled K values. In the first case, it is assumed that the local heterogeneity of K values for sand and silt are lognormally distributed and the probability density function (pdf) of K comes from the unconditional simulation of a multi-Gaussian random function using fast Fourier transform. It is envisaged that the pdf will be constructed from the hydraulic test results from small core samples and may be a spatial Gaussian process. In the second case, the heterogeneous formation is replaced by a homogeneous field by using the mean values of K for sand and silt available in the literature. The steady state simulation is performed using the MODFLOW-2005 code. We apply our approach to a shallow alluvial formation in the Maules Creek catchment of the Namoi river in New South Wales.

Our approach enables the full range of likely values for the critical conductivity parameters to be generated by combining the relevant expert knowledge and indirect data that may exist. It also allows the specific questions into what drives the uncertainty or variability in the upscaled parameters. A series of processing steps involved herein removes the subjective decisions of a single groundwater modeler to generate a range of values for the hydraulic parameters. Each step can be easily modified or assessed independently by the separate party. Our approach shows great potential for simplifying the geological models by only working on the equivalent hydraulic conductivity while still integrating the full geological information.

Keywords: *3D geological modeling, heterogeneity, numerical modeling*

Novelty and challenges in characterizing non-stationary bedforms in large rivers using Direct Sampling

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Abstract: In large rivers, rapid changes can occur in the bed bathymetry. Insight into spatio-temporal patterns of sediment deposition could be gained if the evolution of bathymetry could be monitored with a high spatial and temporal resolution. Unfortunately, such surveys cannot be carried out frequently. This study demonstrates the application of Direct Sampling (DS) to generate high-resolution bathymetry at a high frequency using low-cost measurements.

In this study, high-resolution measurements are conducted using Multi beam echo sounder (MBES), which has the ability to provide very detailed bed features at a spatial resolution of 0.5m x 0.5m. These measurements cannot be acquired at intervals frequent enough to characterize the rapid sedimentological processes. Low-resolution bathymetry is available at frequent intervals by installing depth measuring sensors on boats passing the study reach several times a week. This data is available only along the boat path.

Our approach is based on multiple-point statistics (MPS), which uses a training image (TI) to provide prior statistical and architectural constraining data. In the simulations, the method uses the textural information contained in the MBES high-resolution surveys and the local information contained in the boat-borne low-resolution measurements. Two equally probable alternative training images are mixed to represent different spatial scenarios under two extreme stages of the river bathymetry (high and low flow). To the best of our knowledge, this is the first time two equiprobable training images have been used in a DS simulation to provide the complete range of values for a single intermediate state.

Two types of geostatistical simulations are performed: with and without conditioning data, can be referred as conditional and unconditional simulations, respectively. Unconditional simulations are performed to check the sensitivity of the model parameters for replicating the global bedforms in the river. Once the spatial structures are adjusted in the unconditional mode, the conditional simulations are performed to represent predictions of high-resolution bathymetry for medium-flow. To account for the non-stationarity of the bedforms, the DS simulations are constrained with additional variables. We evaluate scenarios imposing local consistency by including latitude, longitude of the data point in the training image and the distance of points from the left bank. These locational variables provide additional guidance to the DS simulations while looking for patterns in the training image. We also compare our approach of dealing with nonstationarity involving the use of locational variables, with a classical methodology involving trend modeling. The simulation results are evaluated by visually examining the predicted bed features with those expected in the MBES data. The quantitative evaluations of the runs are made based on the Root-mean-squared error (RMSE) and the Relative-mean-squared error (Relative MSE).

Since the low-resolution data are available only along the boat path, the predicted bedforms from the conditional DS simulation are different from those present in the MBES data. To further investigate the reason for such discrepancy, four zones are created covering area slightly and far away from the navigation channel. The errors between the DS simulation results and the reference are estimated in each of the zones separately. The error values are found to increase when moving away from the conditioning data locations from zone 1 to 4. The local data in the narrow region of the navigation channel are found to be useful in producing good predictions but are not enough to predict the global evolution of the bathymetry beyond the correlation range of the spatial variability of the bedform features.

Keywords: *Bathymetry, direct sampling, bedforms*

An approach for developing and comparing empirical methods to model unaccounted losses in river system models

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Abstract: The use of loss functions in river system modelling assumes that river losses can be derived as a function of river flow. An approach has been developed that uses multiple objectives and cross-evaluation techniques to test different loss functions for improvement to river system simulation performances (Figure 1). This approach provides rapid analysis of the loss versus flow relationship and a framework for determining the most appropriate loss function. This method is particularly useful when incorporated with parsimonious modelling paradigms to increase parameter transferability and reduce over-predicting problems that are usually associated with models with large numbers of parameters (Box and Jenkins, 1970). The approach was trialled during the CSIRO Flinders and Gilbert Agricultural Resource Assessment (FGARA) project, where a river-reach model was developed that uses streamflow routing, rainfall-runoff and the Monod loss model for river-groundwater interactions. Twenty-one reaches in Queensland's Flinders regions were jointly calibrated and then re-simulated with the Monod loss model removed. These simulations were modified to include each of five alternate loss function models: (1) a 2-parameter isotonic piecewise-linear (IPWL) loss function; (2) a 5-parameter IPWL loss function; (3) a 10-parameter IPWL loss function; (4) a 10-parameter loss table derived with a quantile-based approach; and (5) a 100-parameter loss table derived with a quantile-based approach. Slight variations of loss function approaches were also tested in attempts to explore more options. The IPWL loss function is designed to have enough flexibility to adapt to the loss characteristics of specific river reaches while still being constrained to realistic behaviour. The results showed that the IPWL loss functions could perform well in both calibration and evaluation periods if there were initial over-estimations of flow and, hence, could potentially be used to pursue alternative parsimonious loss functions.

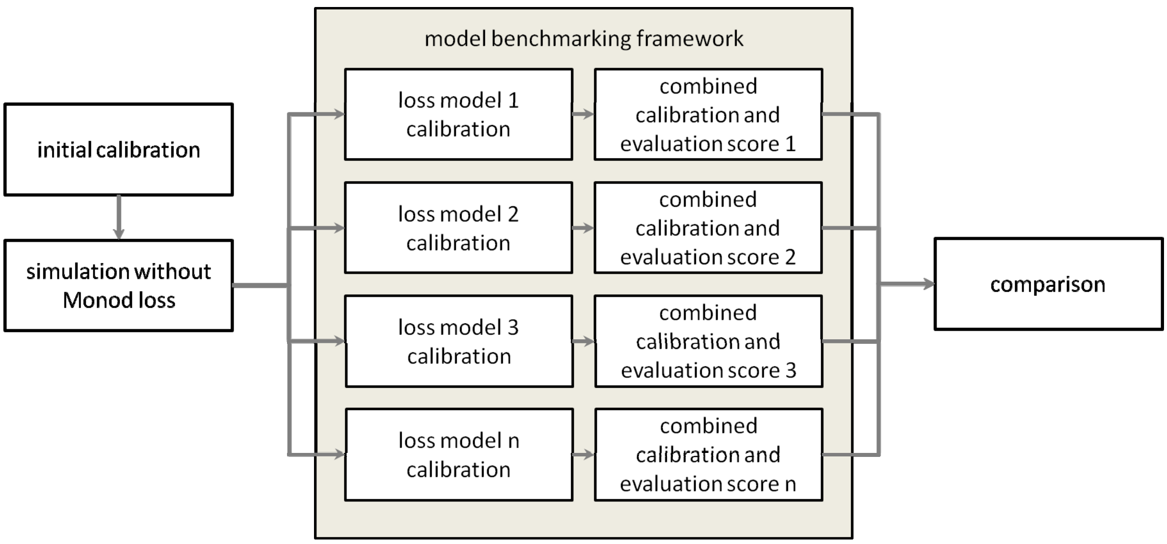

Figure 1. Conceptual flow schematic of the method used to model the different loss functions, including the model benchmarking framework.

Keywords: *Flinders Catchment, loss function, model benchmarking, calibration, river system modelling*

Evaluating the effect of climate change on areal reduction factors in Sydney using regional climate model projections

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Abstract: Design of hydraulic structures requires information on the maximum amount of rainfall that could occur for a particular catchment area over a specific duration. However, design rainfall estimates only provide the rainfall information at a point scale. To transform the point design rainfall to an equivalent design rainfall over the catchment area, areal reduction factors (ARFs) are commonly used. Although there has been some research into the impacts of anthropogenic climate change on design rainfalls, there has been much less work examining the likelihood of spatial changes to design rainfalls which ARFs represent.

This study investigates the impact of climate change on ARFs over the Sydney region by using a high-resolution Weather Research and Forecasting (WRF) model. The WRF model is driven by a General Circulation Model (GCM), which is CSIRO Mk3.5, under current (1990-2009) and future (2040-2059) climate scenarios. The domain of this WRF model extends to the Hunter Valley in the north, Jervis Bay in the south and Orange in the west. The oceanic region on the WRF domain was excluded in this study since the ARFs over ocean are not of much practical use. The study area was then divided into two climatically similar regions: inland and coastal. ARFs were estimated from the model simulations using the modified Bell's method for Annual Exceedance Probabilities (AEPs) from 1 in 2 to 1 in 20. To assess the ability of WRF model to correctly represent the areal properties of extreme rainfall, the modeled ARFs were compared to existing observed ARFs for Australia. It was found that ARFs are simulated well in both global reanalysis and GCM driven WRF simulations with less than 5% error for durations longer than 3 hours.

The assessment of the future change of ARFs was then conducted, and results show that ARFs tend to decrease in the future for durations longer than 2 hours for AEP of 1 in 2 over the inland region. The reductions in ARFs are larger for larger contributing areas. It is conjectured that this could indicate that there are likely to be more small-scale convective storms in the future over the inland region. One of the important implications of this finding is that if the future climate conditions are incorporated into the hydrological structural design and flood risk management, the extent of the reduction of the model predicted precipitation to a catchment scale can be more than that suggested by the ARFs derived for the current climate. Changes in the ARFs for less frequent events were not found to be significant over the inland region. Over the coastal region, the magnitude of the change of ARFs is rather small (i.e. <1%) and insignificant for AEP of 1 in 2, but for AEP of 1 in 20 a clear increasing trend (i.e. ≤ 10%) of ARFs was found. Although these increases were found to be significant for over half of the areas and durations, the spatial variability of the changes is quite high.

Keywords: *Areal reduction factor, regional climate model, climate change*

Applications of Approximate Bayesian Computation in Hydrology

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Abstract: Understanding how uncertainty is manifested in hydrologic predictions is critical for efficient use and interpretation of hydrologic models. It is well recognized that uncertainty arises due to unknown or poorly prescribed model parameters, model structures and hydrologic observations. However, there has been much debate in the hydrological community about the relative merits of various approaches to uncertainty analysis. Of particular interest are two widely used and well-established frameworks for uncertainty assessment: the 'informal' Generalized Likelihood Uncertainty Estimation (GLUE) approach, and the more formal probabilistic (Bayesian) approaches. Recent comparisons of the two methods suggest that, despite philosophical differences in their use, their implementation can be markedly similar.

In this study, we demonstrate that the connection between formal Bayesian inference and GLUE goes beyond operational similarity by examining recent developments in Approximate Bayesian Computation (ABC). ABC algorithms involve the use of a kernel function and the generalized likelihood in GLUE can be thought of as relating to this kernel function rather than to a likelihood. The intent of this study is to encourage cross-fertilization of ideas regarding GLUE and ABC in hydrologic applications and to illuminate the implicit assumptions in different choices of generalized likelihoods. ABC has been the subject of much research for intractable likelihood problems and recent activity regarding ABC extensions and approximations may be of particular interest for hydrologic applications.

A case study is implemented whereby a conceptual rainfall runoff model is calibrated for several catchments with diverse hydrologic characteristics. We demonstrate how various generalized likelihoods may be derived to inform the model calibration under different conditions. A Sequential Monte Carlo (SMC) algorithm is implemented to address the efficiency and robustness of the classical GLUE approach. Our results demonstrate the practical similarity between GLUE and ABC algorithms for hydrologic applications. In addition, the case study suggests how the basic GLUE framework may be extended to address input uncertainty and reduce the sensitivity of results to the choice of behavioral threshold.

Keywords: *Approximate Bayesian Computation (ABC), Generalized Likelihood Uncertainty Estimation (GLUE), hydrologic model, model calibration*

Assessing the non-stationarity of biases in General Circulation Models

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Abstract: General Circulation Model (GCM) and Regional Climate Model (RCM) simulations are widely used to quantify future changes in the climate system and more specifically for water resources impact assessments. There are a number of problems with directly using GCM simulations for these purposes, not least of which is the biases that exist in the current climate simulations compared to observations. Bias correction methods to correct GCM/RCM rainfall projections can consider multiple GCM/RCM outputs and can be easily applied to different regions or climatic regimes.

The major assumption regarding the bias correction approaches is that the biases are constant over time and, therefore, that by estimating the biases for the historical period they can be removed from the future period simulations to yield a non-biased climate change estimate. In this paper, we present the results of preliminary analyses that indicate that for parts of Australia, and some GCMs, the biases in temperature and rainfall statistics do change over the course of time and therefore the assumption of the bias correction methods are violated. Biases in the mean, variance and distribution of monthly rainfall and temperature data over the 20th century have been estimated using the simulations from five GCMs that are part of the Coupled Model Intercomparison Project (CMIP5). Non-statonarity has been assessed using 10-year and 20-year moving windows to compare the observations and GCM simulations. The biases are being assessed at monthly and annual time scales, at the native GCM resolutions. Change point tests have also been applied to test if the non-stationarity is caused by abrupt changes or more gradually varying trends. For several of the GCMs where there are multiple initial conditions and perturbed physics ensembles, biases across the different realisations of the same GCM have been compared.

The issue of biases at different time scales is also considered as many bias correction methods do not take into account that oscillations on different time scales are caused by disparate physical mechanisms. This paper quantifies the extent of non-stationarity in the biases and provides some initial suggestions on how this issue may be addressed in improved bias correction techniques.

Keywords: *Bias correction, non-stationary bias*

Hydrologic data networks, connections, and dynamics

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Abstract: Hydrologic data networks (e.g. raingage and streamflow data monitoring networks) and their dynamics play a key role in a wide range of water resources, environmental, and ecosystem studies. Despite the significant advances made during the last century or so, identifying and establishing optimal hydrologic data monitoring networks, understanding their connections and dynamics, and estimation of data at ungaged locations continue to be extremely challenging. Part of this difficulty comes from our lack of comprehension of the intrinsic nonlinear and complex behaviors of the hydroclimatic system and processes. On the other hand, however, the inherent limitations in our existing modeling approaches also contribute to this difficulty, as such approaches are largely reductionistic in nature and often lack generality for universal applications. A holistic approach to study hydrologic data networks, and hydrologic networks at large, is urgently needed.

This study aims to develop a novel and generic approach for studying hydrologic data monitoring networks, based on ideas gained from recent developments in the study of complex systems, especially 'networks.' The approach is different from the existing approaches in concept, form, and methodology. The approach is developed based on, validated for, and tested on many rainfall and streamflow monitoring networks of varying size, structure, and complexity, particularly those from Australia and the United States. These networks cover different climatic, topographic, catchment, and other factors, and, hence, allow useful and reliable interpretations about their dynamics.

As for the shape of the network, the networks studied here include both irregular networks (e.g. irregularly-spaced gage-based rainfall and streamflow monitoring networks) and regular networks (e.g. equal and regularly-spaced satellite-based rainfall monitoring networks). As for the network size, large (e.g. nation-wide), medium (e.g. regional), and small (e.g. local) data monitoring networks are considered. Study of such a diverse array of networks allows a systematic examination of the structure, connections, and dynamics of hydrologic data monitoring networks. Particular emphasis is also given to examining the physical relationships within the networks.

The outcomes of this network-based approach offer important information at the most basic levels for studies associated with rainfall and streamflow data monitoring networks, including location and density of such monitoring networks and interpolation methods. These include, among others: (1) assessment of whether or not new measurements (or estimation) of data is necessary or effective for any region; (2) identification of the most appropriate and effective data estimation (e.g. interpolation, extrapolation) method for a region; (3) identification of the critical points (hotspots) or areas that offer the most significant benefits in terms of data monitoring, including installation of new monitoring stations; (4) classification of regions in terms of network connections and other salient properties; and (5) identification of the appropriate type and complexity of mathematical models for hydrologic data monitoring networks.

The outcomes of the present study also lead to a broader discussion on the role of network-based approaches in hydrology and water resources in general, including for studying hydrologic cycle and water supply and distribution networks.

ACKNOWLEDGMENTS

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Keywords: *Hydrologic data networks, rainfall, streamflow, complex systems science*

An approach to detecting associations between variables for hydroclimatic forecasting

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Abstract: Predictor selection is an essential part of hydroclimatic forecasting process based on regression models because calibration overfitting could arise from a large initial number of parameters, such as ocean-atmospheric state variables. This study presents a methodology for identifying non-specific associations between hydroclimatic variables as part of a predictor selection process. The approach is based on the significance level p derived from permutation testing of the mean nearest neighbour statistic Δ_n as obtained from a scatter plot with the forecasted variable on the y axis and a potential predictor on the x-axis. The essence of the approach is to test against a no-association null hypothesis, as defined by random rearrangement of the x-variable data set.

The statistic Δ_n is defined as the mean Euclidian distance between each data point and its nearest neighbour in the scatter plot. That is $\Delta_n = 1/N \sum_{i=1}^{N} d_{i,}$ where N is the number of data points and d_i is the distance from an i-th point to its nearest neighbour. Once Δ_n is calculated for the original data set, random permutations of the points are carried out with the new statistic $\widetilde{\Delta_n}$ calculated each time. The p value is the proportion of times that $\widetilde{\Delta_n}$ is less than Δ_n. A sufficiently small p value, say less than 0.05, leads to rejection of null hypothesis of no association between the two variables concerned. The number of random permutations needed for required precision of p is determined as usual from the binomial theorem. The number of data points does not affect the required number of permutations. However it does influence total computational time because more calculations are needed to obtain $\widetilde{\Delta_n}$ for larger values of N.

The approach enables detection of general associations between variables without explicit definition of the nature of association. This could include, for example, functional dependence or clustering as illustrated in Fig. 1. Both cases here would give near-zero p values (larger values of nearest neighbor distances with randomization) but a linear correlation measure like r would not detect the association.

The method is entirely non-parametric and does not require estimation of some assumed underlying data structure or any further parameter estimation. It could be used as a screening tool for preliminary identification of associations between plausible predictors and forecast variable such as lake inflows. Of course, simply establishing undefined significant association will not necessarily translate to practical prediction value and further work is required to convert associations into practical prediction models.

A preliminary application of the methodology seeks to identify variables associated with lake inflows in the Waitaki catchment, New Zealand. The aim here is to detect potential predictors by finding associations with respect to monthly-averaged gridded Pacific variables (sea level pressures and geopotential heights).

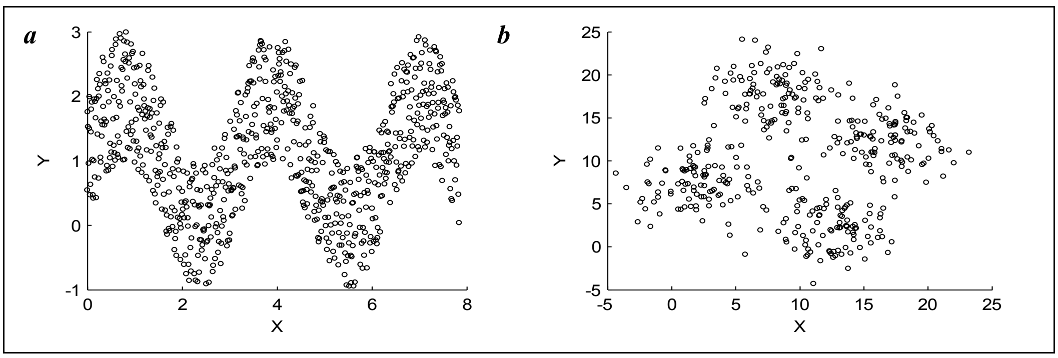

Figure 1. Functional (a) and clustering (b) types of associations. Pearson correlation coefficients and significance levels are respectively ***a***: $r = -0.12$, $p = 0.53$ ***b***: $r = -0.04$, $p = 0.79$. The corresponding significance levels for the minimum nearest neighbour test are ***a***: $p = 0.001$, ***b***: $p = 0.007$.

Keywords: *Association measure, permutation test, predictor selection*

Groundwater Drought Assessment for Barind Irrigation Project in Northwestern Bangladesh

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Abstract: Natural droughts are recurring phenomena that usually affect nearly all components of the hydrological cycle. Groundwater (GW) drought is a particular type of hydrological drought. It is generally caused when the GW heads in an aquifer fall below a critical or threshold level over a certain period of time due to natural and/or human induced causes and interventions. In the recent past, there was increased frequency of droughts in Bangladesh. Particularly, the northwestern region of the country was severely affected by the occurrence of droughts and high variability in rainfall. The country's largest groundwater-fed irrigation project, Barind irrigation project is located in this region, wherein about 75% of irrigation water comes from the GW source. The national water policy of Bangladesh has also suggested the GW development for irrigation in both the public and private sectors. Therefore, it is essential to investigate the occurrence and distribution of GW drought severity for the effective GW resource management of the Barind Irrigation Project in the northwestern Bangladesh.

Barind Irrigation Project is located within the Barind Tract area, which covers most parts of seven northwestern districts, namely Bogra, Dinajpur, Joypurhat, Naogaon, Pabna, Rajshahi, and Rangpur under Rajshahi division in Bangladesh. Barind Multi-purpose Development Authority (BMDA) reported that 6000 deep tube wells and 66000 shallow tube wells were installed by the year of 2000 for irrigation development. The GW dependent irrigation system in the area has reached a critical phase as the GW level has dropped below the depth of the shallow tube wells in many places. The recently published GW zoning map indicates that a record of 60% irrigated croplands in Naogaon district have become critical for shallow tube well operation. The overexploitation has caused the GW level falls to the extent of not getting fully replenished by the rainfall recharge. If this over-utilization of the Barind aquifer continues, it may result in its exhaustion after few years that will have certain impact on the agriculture-based economy of the country. Hence, the main objective of this study is to assess GW drought at a specific part (Naogaon district) of Barind Irrigation Project in the northwestern Bangladesh, where GW scarcity is increasing day by day.

Available GW level and climate (rainfall and temperature) data are collected from the relevant organizations in Bangladesh. The cumulative deficit (CD) approach from threshold GW level is applied to evaluate the drought severity. Different threshold levels (70%, 80%, and 90%) of the mean GW level for the whole area are computed to visualize the drought severity in the GW system. The estimated CD values at different monitoring wells are interpolated in the ArcGIS platform to produce the spatial GW drought maps, each of which represents the drought severity for each specific threshold value.

Meteorological drought has been computed by the Standardized Precipitation Index (SPI) method and wet events are identified from time series data of precipitation. The SPI is used to identify any likely relationship of GW drought and wet events with the GW level. Similarly, temperature records are used to explore any possible connection between GW and climate in the study area.

Spatial maps of GW drought for different threshold levels indicate that GW drought is a frequent event in most part of the study area and the northern part is free from drought events. The GW hydrographs for most of the monitoring wells exhibit significant declination of GW table in the study period because of the extensive GW withdrawal from the underground aquifer, which is the main reason for the GW drought occurrence. The study finds that GW drought is correlated to the meteorological drought event, which indicates that the deficiency in rainfall may exacerbate the GW drought conditions. The study finally recommends that development and conjunctive use of GW and surface water resources should be undertaken and practiced to satisfy the increased irrigation water demand in the Barind Irrigation Project as well as to reduce the growing pressure on the GW reserves in northwestern Bangladesh.

Keywords: *Barind Irrigation Project, Cumulative Deficit Approach, Groundwater Drought, Meteorological Drought, Standardized Precipitation Index*

Introducing a Pressure Index for Water Distribution Networks' Augmentation Planning Strategy

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Abstract: Potable Water Distribution Systems (WDS) need augmentation strategies based on a determined and pre-defined time intervals. The main aim of potable water systems augmentation is maintaining the standard and acceptable level of service after occurrences of increase in design serviced population, asset ageing and/or serviced area. It is obvious that systems augmentations require significant amount of budget allocation, which is the main constraint for the water authorities for the implementation of any augmentation plan.

In general, two main factors are playing roles in planning of WDS augmentation strategies; namely, the parameter of "Level of Service" on one hand and the factor of "Augmentation Cost" on the other. The main goal of a proper planning in a WDS is the prediction of a system's water demand in future and suggestion of an appropriate and efficient solution for the predicted demand.

Till now, no research has been conducted to establish a relationship between "Level of Service" and "Augmentation Cost". In this paper, a new index is introduced to measure the level of service of a water distribution system from its pressures point of view. Since there is no existing factor for the rating of a water network from its pressures point of view, a new factor named "Pressure Index (PI)" incorporating number of pipe nodes for five different pressure regimes is defined.

The PI factor is expected to show improvement after a WDS augmentation which is the indicator of that WDS' pressures improvement and therefore the effectiveness of proposed planning scheme. As a case study, three existing water network systems in Castlemaine area near central Victoria is investigated and relationship with the 'augmentation costs' and PI factors is presented.

Keywords: *Level of service, water distribution system planning, augmentation cost, pressure index*

Cost-benefit analysis of farm water storage: Surface Storage versus Managed Aquifer Storage

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Abstract: Managed Aquifer Recharge (MAR) has been demonstrated to offset groundwater demand in many locations around the world. At each location where MAR has been successfully undertaken, there are unique hydro-climatic, socio-economic and institutional conditions. This has resulted in a variety of methods to recharge aquifers. Despite its physical potential, there has been limited uptake of MAR in Australia. Limited knowledge of the actual costs and benefits from MAR projects is a major barrier to the uptake of MAR. The cost of an MAR scheme is highly variable across regions because of several hydrogeological and climatic influencing factors, such as the rate of recharge, type of aquifer, water source, water quality and method of water treatment. The comparative cost of MAR with regard to surface water storages is poorly known in Australia. Published MAR cost estimates are local and situation specific, making cost comparison difficult across regions. The aim of this paper is to estimate the economic efficiency of using stored water in surface dams to that stored in an aquifer using MAR. The study estimates, for the Lower Namoi cotton irrigation district in New South Wales, Australia, the relevant costs and benefits and compares net irrigation benefits under three different water storage methods – surface storage in farm dams, aquifer storage using pond infiltration and aquifer storage using injection wells. Preliminary results indicate that aquifer storage is financially viable. But the maximum cost of aquifer storage, regardless of MAR method, should not exceed 500 $/ML to achieve the breakeven point, that is the point at which the cost of aquifer storage is equal to the resulting farm benefits. Sensitivity analysis is performed on key variables such as the infiltration rates, costs of pumping and cotton prices. Infiltration rates and pumping costs are found less sensitive, while cotton price was, not surprisingly, found highly sensitive to the NPV. A 50% reduction in infiltration rates and a 25% increase in the cost of pumping does not significantly affect the NPV. However, a 10% and 25% reduction in the price of cotton renders a 27% and 78% reduction in the NPV, respectively.

Keywords: *Groundwater, managed aquifer recharge, cost-benefit analysis*

New approaches for groundwater salinity management and allocation reductions

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Abstract: The Tintinara-Coonaplyn Prescribed Wells Area (PWA) is located in the upper South East of South Australia approximately 200 km southeast of Adelaide and covers an area of 3,423 km^2. It overlies part of the Murray Basin which is a large sedimentary groundwater basin covering 300 000 km^2 of southeastern Australia. Managers of the groundwater resources in the PWA are dealing with a number of complex issues. These issues include groundwater salinisation, groundwater level declines due to below average rainfall and over-allocation in some management areas.

Lucerne, the major irrigated crop grown in the area, has a high water use. Groundwater extracted from a shallow Quaternary limestone aquifer is applied to the crop by flood and pivot irrigation, and as water is drawn up through the root system, most of the dissolved salt is not taken up by the plant and accumulates in the root zone. This salt then percolates back down into the shallow aquifer during subsequent irrigation applications or from rainfall recharge, resulting in increasing groundwater salinity due to the recycling of the irrigation drainage water. Over 50% of irrigation wells sampled show an increase due to this process.

In 2003, the first Water Allocation Plan (WAP) for the Tintinara-Coonaplyn Prescribed Wells Area which was developed by the South East Catchment Water Management Board, was adopted to provide a management framework for the groundwater resources. Typically, problems arising from over-extraction from aquifers are managed by reducing such extractions to sustainable levels. However, it was recognised that the degradation due to recycling is caused by application of water to the crop rather than the physical removal of water from the aquifer, and hence a new approach was required. A buffer zone method was instigated in the WAP to prevent concentrations of irrigation (and the resultant salt accessions) in any given area and allow dispersion and dilution of the salt added to the aquifer by rainfall recharge. This method will also prevent excessive drawdowns in water levels caused by pumping which may prevent lateral groundwater flow through the aquifer which removes salt from the region.

The 2003 Plan also limited extractions in the main Tintinara Management Area to the current levels at that time although due to a lack of meter data, the exact volume of those extractions was not known. Theoretical crop irrigation requirements (TCR) were used to determine the volumetric allocations given to irrigators. An area limitation was also imposed so that the area irrigated could not be increased. This limitation proved crucial in the pursuit of sustainable management, as six years of metered data subsequently showed that actual extractions were only about 45% of the TCR for the same area of irrigated crop. This outcome is consistent with trends observed in other areas of SA.

The South East NRM Board reviewed and amended the WAP which was adopted by the Minister in 2012. The over-allocation issue was addressed by recalculating the TCRs using more recent information, setting a reduction target for allocations and involving the 40 irrigators in determining the methodology for meeting that reduction target. This process was very successful because when the WAP incorporating these water allocation reductions had finished public consultation, there was not one submission from an irrigator against the Plan. There are several factors that contributed to this successful outcome.

- The metered extraction data clearly showed the over-allocation, even during the very dry years
- The agency expert had built up a good relationship and trust with the irrigators over 10 years
- This led to the irrigators having a good understanding of the hydrogeology and the management issues
- The irrigators worked with the NRM Board and had a say in how the reductions were carried out
- The reductions were staged over several years so that irrigators had time to adjust their operations.

Keywords: *Groundwater management, over-allocation, salinity*

Cost estimates in cost-effectiveness analysis of water quality monitoring systems

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Abstract: Traditional cost-effectiveness analysis requires obtaining estimates of the cost and effectiveness of a monitoring program or design and weighing them against each other. With obvious technical soundness of the approach, its complete utilization, however, is still very limited. The limitations should be attributed firstly to the necessity to express both the cost of a monitoring program and its effectiveness in quantitative terms using at least the same measurement units, if the monetary estimates are not available. Although the cost estimation is considered as a simple technical exercise, it is worth noting that comprehensive and systematic guidelines for developing cost estimates of an environmental monitoring program are not available. In most of the cases, when evaluating the cost of a monitoring program, the authors take into account only some of the components and even for those components estimates are very approximate or are not available at all. When monetary estimates of the effectiveness and the cost of a monitoring program are unknown, the direct cost-effectiveness analysis can be replaced by an operation research model, solutions to which generate efficient monitoring designs. One of the two possible articulations of the optimization problem is to minimize the cost of a program or design, so that the effectiveness of the program meets established requirements. In this case, mathematical articulation of the cost serves as the goal function. The effect of a particular expression for this function on the designs developed as solutions of the constraint optimization problem is investigated in the study.

The analysis of the scientific and technical literature on cost-effectiveness analysis of environmental and ecological monitoring programs revealed different approaches to cost estimates with the emphasis on the necessity to distinguish between budgetary costs, showing how the allocated money is spent and economic costs which broaden the consideration and add the opportunity cost, i.e. the missing benefits of other activities due to allocating the money to monitoring an environmental resource. The comprehensive cost assessment should include both components, however, the approaches to complete cost estimates are yet to be developed. Since the cost function is intended for application in the operation research model for developing efficient temporal monitoring designs, only budgetary cost is considered under an assumption that variable cost is associated solely with water sample collection and processing. The rest of the cost components are independent of the number of taken samples and constitute the fixed cost. In all suggested approaches, the cost of a program is defined as a non-negative, non-decreasing function of the number of samples collected or observations made. Seven mathematical expressions were developed with the same properties and their parameters were identified based on rough estimates of the costs of operations of a water quality monitoring system. The effect of the cost articulation on the developed designs was investigated through a series of computational experiments, where the designs were developed as solutions of the optimization problem with different mathematical expressions for the goal function.

The results of computations showed that the solutions of the optimization problem are invariant of the expressions used for the cost function. The designs for monitoring water constituents remained unchanged when the developed expressions with different mathematical functions were substituted into the cost function. The study showed that, the optimal number of observations is independent of the cost of a monitoring design. It is determined by the level of effectiveness which must be attained by the design. The results validate the replacement of the cost-effectiveness analysis in its classical form by an operation research model which minimizes the total number of observations with the limit set for required effectiveness. Solutions of this model will generate designs with minimal cost.

Keywords: *Monitoring designs, cost-effectiveness analysis, constraint optimization, water quality*

A water resource allocation model for an area in the Murray-Darling Basin

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Abstract: The Murray-Darling Basin (MDB) is a large and complex region. It is just over a million square kilometres in size, has a diverse range of landscapes, ecosystems, land uses, and climates, including 16 Ramsar Convention Wetlands of International Importance. As at November 2010, 20 of the 23 major river valleys of the Basin were in poor to very poor ecological condition. The MDB supplies water to approximately 3.4 million people and various industrial activities. These use 4% of the water diverted from the Basin's rivers, the remaining 96% of diversions is used for agricultural irrigation. The MDB contains around 65% of Australia's irrigated land and around 40% of the country's farms. It produces $15 billion worth of produce annually or approximately 40% of Australia's gross value in agriculture. The MDB has been home to Aboriginal peoples for at least 50,000 years, and 34 major Aboriginal nations maintain their traditional lands within the Basin. The MDB is divided between the southern and eastern Australian states of New South Wales, Victoria, South Australia and Queensland, and includes the Australian Capital Territory. Each state government has its own system of water entitlements and management. Historically, this has led to over-exploitation, a common problem with open access resources.

To address this and other issues, the optimal and equitable allocation of water resources to various users in one of the MDB's Water Resource Planning Areas (WRPA) is examined. The WRPA selected was the Murrumbidgee River. The Murrumbidgee is the second largest river in the Murray–Darling Basin and represents approximately 8% of the total area of the Basin. The Murrumbidgee catchment contains the national capital, Canberra, and Wagga Wagga, New South Wales' largest inland city. The Murrumbidgee catchment is home to sites of international, national and regional environmental importance, including two Ramsar-listed sites: Fivebough and Tuckerbil Swamps and Ginini Flats Wetland Complex, and the Mid-Murrumbidgee Wetlands and the Lower Murrumbidgee Floodplain.

This work is the result of collaboration between staff and undergraduate students in a capstone Operations Research subject. A linear programming formulation of a multiple-objective, network optimisation problem is used. This model captures the essential aspects of the operation of the water resource system and the social, economic, and environmental objectives specific to the area. Weighted sum goal programming is used to convert the multiple-objective decision problem into a single objective problem. The formulation has elements in common with the model used in Victoria and South Australia, the Resource Allocation Model or REALM, where network linear optimisation is used to model planning areas in the MDB. The formulation of the weighted sum goal program involves rainfall run-off submodels that provide information for the balance equations. Estimation of these submodels is a nontrivial task.

This model then provides a useful adjunct to the Murrumbidgee Computer Aided River Management Project (CARM). CARM encompasses a suite of projects seeking to "integrate many pieces of real time water management data to improve the efficiency of river operations, ensuring the correct amount of irrigation water is delivered to the right place at the right time". It is scaffolded by simulation-based software. Many integrated water resource management tools use a combination of optimisation and simulation approaches to determine water quantity decisions, with the outputs of the optimisation models serving as inputs to the simulation models.

To date, the literature addressing compromises between water users is light. The current work represents a first step towards more sophisticated and realistic models of WRPAs, including fuzzy and stochastic optimisation.

Keywords: *Water allocation, network optimization, linear programming, multiple-objective decision-making*

Modelling Groundwater Dependent Ecosystems in the Willunga Basin, South Australia

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Abstract: The challenge of groundwater management is to establish sustainable extraction regimes that provide acceptable levels of protection of economic, social and environmental assets and values that depend on the resource. A key knowledge gap relates to how groundwater resource management affects the integrity and survival of groundwater dependent ecosystems (GDEs). This study involves the development of habitat suitability models that assess the suitability of the groundwater regime in the Willunga Basin for supporting GDEs. GDE species in the Basin are classified into five functional groups according to their water requirements and tolerances. Habitat suitability index curves were developed for the five groups based on species observations and descriptions reported in literature. The index curves are described by a set of constraints that quantify the minimum and maximum bounds of values, reflecting the uncertainty of the relationship between groundwater regime and species habitat suitability. Alternative mathematical translations of descriptions of the groundwater requirements of species were also tested. The models were applied to assess the habitat suitability of the five functional groups at 35 sites in the Willunga Basin in terms of the groundwater regime (results are summarised in the figure below).

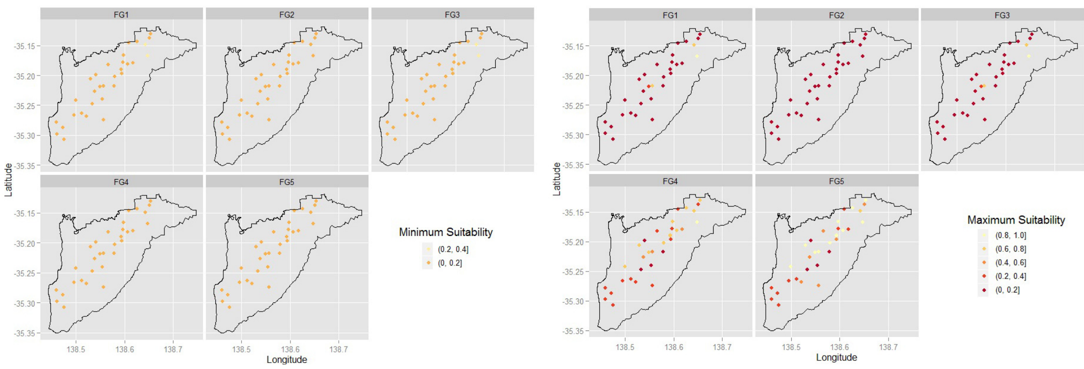

Figure 1. The minimum (left) and maximum (right) habitat suitability values for the five functional groups of plant assemblages across 35 sites in the Willunga Basin.

The models were able to identify sites that have unsuitable or poorly suited habitat for most of the functional groups with high confidence. However, there was low confidence in identifying sites with good habitat. The results of test runs of the alternative constraints suggested that the models were relatively robust. The sites were ranked by partial order, however if the plausible index bounds of sites overlapped, uncertainty remained about the ranking implied. Large bounds indicate gaps in knowledge that require further research. The model was applied to detect areas where GDE habitat may have been lost through time. Potential applications of the model include identifying sites for further monitoring or research. Future work should include the incorporation of more attributes of the groundwater regime, water quality and other environmental factors to describe habitat suitability, the use of ecological data for calibrating or validating the model, and the involvement of experts to set and review the model constraints. This modelling approach allows sites to be evaluated from an ecological point of view even with high uncertainty.

Keywords: *Ecological modelling, groundwater dependent ecosystems, habitat suitability model, uncertainty*

Representing flow mixing demands in a multi-nodal CDDP model of a mixed used catchment

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Abstract: Constructive dual dynamic programming (CDDP) can be used to optimise a multi-nodal water system, or to clear a multi-nodal water market in the presence of competing consumptive demands, such as irrigation for farming, and non-consumptive demands, such as hydro-power generation. In this setting, CDDP is used in a two-stage process. First a deterministic multi-node version of the algorithm is used to construct a series of demand curves for release (dcr) under various catchment inflow scenarios. This is termed the 'intra-period' problem. Then a stochastic version of the algorithm uses the constructed dcr's to optimise the system, or clear the market over multiple periods, under uncertainty. This paper outlines the intra-period multi-node CDDP algorithm, and shows how to adapt this to address uses with water-mixing requirements, such as water returned to the river after being used for cooling a thermal power plant.

All cost and benefit functions at the nodes are converted to net demand functions, i.e., marginal net benefit as a function of water supplied. For this, the nodal marginal value (or bid) information is re-cast to form net demand curves, and the arcs re-oriented towards the reservoir. Then the algorithm constructs the intra-period demand curve for release (dcr) by sequentially forming marginal water value curves at each node, passing these curves towards the reservoir. Arc flow bounds may limit the opportunities for using water at the nodes. Consumptive users extract water from the system, so each unit of water flow can only be used for a single consumptive use. A non-consumptive user transfers water from one node to another, extracting some benefit (e.g. from hydropower generation), or incurring some cost (e.g. for a pump). Costs can be associated with arc flow bounds and distributary demands to represent in-stream and environmental reserve flows enforced using penalty costs.

High temperature return flows from thermal power plant cooling can affect the downstream ecosystem. As a result an additional flow past the thermal station is needed to control the temperature. The mixing flow required can be modelled as a fixed ratio of heated to unheated water. The paper explains how to extend a CDDP model to incorporate flow mixing externalities into the model, using multiple parallel arcs. The model assumes a single long-term storage reservoir embedded in a catchment with a "tree-like" topology. Consumptive demands occur at the nodes. Non-consumptive demands appear on arcs. Cooling and temperature control flow demands are represented as parallel arcs assuming that an upstream flow unit can be diverted to any arc of our choice, but other types of flow splitting are discussed. The deterministic CDDP algorithm then forms a net conditional dcr for each node that implicitly trades off the marginal value of all uses, to maximise total value, or clear the intra-period market. That dcr can then be incorporated into a stochastic CDDP algorithm to construct (inter-period) marginal storage values for the reservoir (and implicit release/allocation schedules for the entire catchment) over the entire planning horizon.

Keywords: *Water resource management, water markets, constructive dual dynamic programming, environmental management*

Evaluating watershed development impacts on physical capital using household surveys and Bayesian networks

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Abstract: The wellbeing of households in rural India is heavily dependent on the condition and accessibility of land and water resources. In the drier regions of India, in particular, the scarcity and deterioration of these resources has placed added pressure on vulnerable households, limiting their capacity to attain sustainable livelihoods. Livelihood assessments typically describe assets in terms of their contribution to financial, human, natural, physical and/or social capital. Physical capital assets, such as wells and livestock, not only directly provide these households with access to water and food but also create flows that increase stocks of other types of capital (e.g. financial capital). Watershed development (WSD) programs are one avenue the government of India uses to improve both livelihood opportunities for rural communities and the management of water resources and agricultural and forest lands. Traditionally, WSD has been designed and implemented at the micro-scale (<1500 ha). However, concerns have been raised about the effectiveness of the WSD programs implemented at this scale as well as negative externalities on hydrologically connected villages outside of the implementation area. Reflecting these concerns, the Indian government now promotes WSD design and implementation at larger scales.

The Australian Centre for International Agricultural Research (ACIAR) is funding a project to investigate socio-economic and environmental impacts of WSD programs at the meso-scale (1500-10000 ha). An integrated modelling approach is being used to assess the beneficial and negative impacts of WSD interventions on household livelihoods and the natural resource base. Bayesian networks (BNs) are being used to develop models of drought resilience of alternative livelihood strategies across household classes and to analyse the influence of WSD on these households.

Two types of household surveys were conducted as part of the meso-scale project. One type focused on quantifying household attributes prior to and since WSD implementation. The other focused on establishing a link between a measure of household resilience and a smaller set of key household attributes. This paper shows how these surveys can be used to assess WSD effects on physical capital within a BN framework (Figure 1). The resilience survey is used to give evidence that agricultural tools are the least resilient physical capital. The full survey is used to show that WSD seems to support well ownership. This result is then connected with resilience survey results to demonstrate that this leads to increased resilience of households.

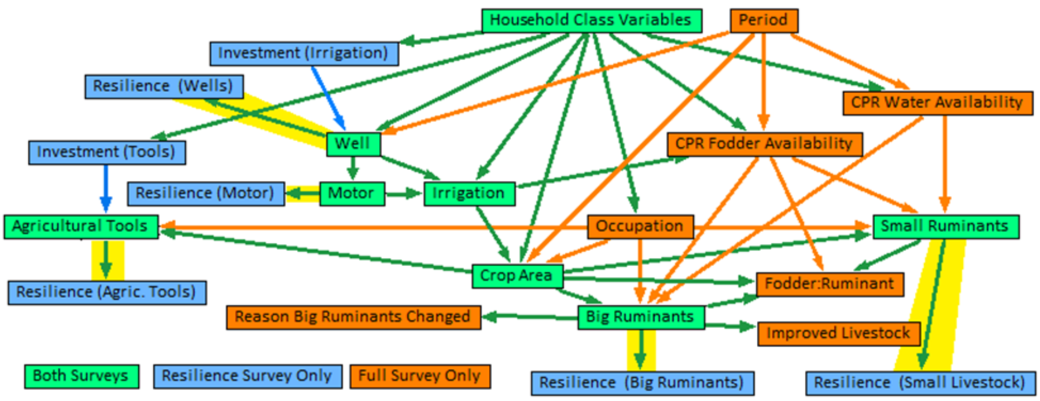

Figure 1. Influence diagram of a Bayesian network model of stocks and resilience of physical capital assets.

Keywords: *Watershed Development (WSD), Resilience, Bayesian Networks (BNs), Household surveys*

Forecasting Daily Reference Evapotranspiration for Shepparton, Victoria, Australia using Numerical Weather Prediction outputs

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Abstract: Farmers and irrigation system operators make real-time irrigation decisions based on a range of factors including crop water requirement and short-term weather forecasts of rainfall and air temperature. Forecasts of reference crop evapotranspiration (ET_O) can be calculated from numerical weather prediction (NWP) forecasts and ET_O has the advantage of being more directly relevant to crop water requirements than air temperature. This paper aims to discuss the forecasting ability of ET_O using outputs from the Bureau of Meteorology's operational NWP forecasts derived from the Australian Community Climate and Earth System Simulator – Global (ACCESS-G). The daily ET_O forecasts were evaluated for the Shepparton Irrigation Area in Victoria. Forecast performance for ET_O was quantified using the root mean squared error (RMSE), coefficient of determination (r^2), anomaly correlation coefficient (ACC) and mean square skill score (MSSS). Lead times of daily ET_O forecasts up to 9 days were compared against ET_O calculated using hourly observations from the Shepparton airport automatic weather station. It was found that forecasting daily ET_O was better than using the long-term monthly mean ET_O for lead times up to 6 days and beyond that the long-term monthly mean was better. The average MSSS of ET_O forecasts varied between 64% and 4 % for 1 to 6 day lead times, respectively. The most influential forecast weather variable for daily ET_O forecasts was mean wind speed, air temperature and incoming solar radiation for 1, 2-3 and 4-9 day lead times respectively. Also, it was found that the forecast performance for incoming solar radiation and mean wind speed was relatively poor compared with the air and dew point temperatures.

Keywords: *Reference evapotranspiration, forecasting, Numerical Weather Prediction, FAO56.*

Advancing Ecological Modelling Tools for Application in Water Resource Planning

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Abstract: Evaluating ecological outcomes as a consequence of alternative hydrologic regimes has been limited to a set of modelling approaches that typically describe hydrologic habitat quality. To enhance our ability to predict change spatially and temporally, there is a pressing need to advance ecological modelling methods to fulfill water resource planning needs. The most pressing of limitations of existing ecological modelling tools used in water resource planning include the poor representation of spatial and dynamic processes in predicting ecological outcomes. This limits the exploration of likely ecological consequences in systems when hydrologic watering requirements are 'not met', fails to represent the connectivity between assets, and lacks representations of hierarchies within ecological systems, such as links between vegetation condition and ecosystem productivity.

Outputs of most existing approaches are still preference-based, non-spatial and sensitive to the model structure. To model the demands of, and changes in ecological outcomes as a consequence of alternative hydrologic regimes, the capability to predict changes in populations through space, and the viability of these populations through time is needed. Here, we use the development of a fish population response model and a spatial habitat suitability vegetation model as examples of how these approaches can deliver to the advancement of ecological response modelling in water management frameworks.

Metapopulation response models, incorporating life-history dynamics and ecological requirements of flow have not been widely applied in riverine ecosystems, despite many of the questions being posed by water managers relating to spatial population mosaics and population viability through time. With fish populations likely to change in response to different flow scenarios and fish being considered as connected communities, they provide an ideal focal grouping for developing a metapopulation model. Through development of a fish population response model, we outline how improvements can be made upon the existing techniques which do not consider population dynamics as responses to environmental conditions, including the consideration of connectivity between populations, dynamic modelling of both population state and response, and consideration of species ecological traits incorporating life-history processes.

Floodplain vegetation models often assume a static distribution of vegetation in the landscape, with model outcomes being limited to condition, or have little to no spatial representation of vegetation persistence linked with management scenarios. Here, we discuss the development of habitat suitability model based on species watering requirements, using floodplain inundation modelling. We demonstrate how this model can be used to predict the impact of management scenarios, including determining hydrologic requirements and the potential outcomes of alternative hydrologic regimes. We also show that with further development we can predict size classes and condition of vegetation on floodplains through time and space in a dynamic population model.

This work demonstrates the need for developing tools for assessing ecological responses for freshwater dependent ecosystems and ecological communities, considering spatial and temporal predictions of ecological outcomes under different hydrologic regimes. We discuss how these approaches provide potential advancements for application within water resource planning frameworks, and in particular, in hydrologic optimisation and scenario evaluation.

Keywords: *Water resource management, population viability models, habitat suitability models, flow scenario, environmental response modeling.*

Multi-objective decision making for basin water allocation

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Abstract: Due to the significant role of water use in socio-economic development, competition for a larger share in water allocation is intense among stakeholders in watersheds. In this paper, three optimization models are developed to explore the optimal allocation of water among users, thus to resolve water conflicts in watersheds. The first model is a linear programming model. The objective function of this model maximizes the basins' revenue. The second model is a multi-objective optimization model. The objective functions of this model maximize the marginal value of water for stakeholders when environmental water supply is a constraint in the model. The third model is also a multi-objective programming model. Three objective functions; maximizing a basin revenue, minimizing the environmental water shortages, and minimizing water transfer from upstream area to downstream region are considered. These models are applied to the Sefidrud Basin, a watershed with eight administrative provinces, each considered as a stakeholder for the modelling. The formulations of three water allocation models are presented and the results of their implementation are compared. The results from the third model show that it would be able to supply more water to agriculture than other models if water authorities would not want the full satisfaction of environmental demand. In other words, if environment is taken into account as a stakeholder, for whom water shortages are acceptable, the third model is recommended. The comparison of the first and the second models reveals that the second model allocates water to stakeholders more equitably than the first model. In the case of the second model, the percentage of maximum and minimum water shortages for the Sefidrud Basin's stakeholders are 71 and 20, respectively, in comparison with 81 and 8 provided by the first model. Hence, we recommend using the second model for resolving water conflicts in watersheds when the satisfaction of environmental water requirements is crucial for water authorities. The policy of water authorities on environmental water satisfaction is a key factor determining the water allocation pattern of the Basin. Therefore, the issue of whether any shortages in environmental water supply are tolerable should be resolved before any decision related to water allocation is made.

Keywords: *Water allocation, linear programming, multi-objective programming, conflict resolution*

Dams and development: A tale of the developing world

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Abstract: The demands for freshwater around the world have and continue to increase due to a range of factors, including population growth, improvement in living standards, increase in industrial and agricultural activities, degradation in water quality, and our increasing recognition on the need to sustain the ecosystems (including meeting environmental flow requirements). This is particularly the case in the developing world, such as Africa, Asia, the Middle East, and South America. However, meeting our water demands has been extremely difficult, since there are not only significant variabilities in rainfall and river flow in both space and time but also enormous differences in the availability of natural surface and subsurface storages (e.g. lakes, glaciers, aquifers) among different regions. As a result, large-scale storage and distribution of water has become an absolute necessity. In this regard, large dams have and continue to play a vital role.

Large dams offer great benefits, meeting various water demands of billions of people around the world. For instance: (1) large dams generate about 20% of the world's total electricity supply — one-third of the countries in the world rely on hydropower for more than half their electricity supply; and (2) half of the large dams exclusively or primarily serve the irrigation demands in regions around the world — about 30–40% of the over 270 million hectares irrigated worldwide rely on dams. Notwithstanding these benefits, however, there are also great environmental and socio-economic costs associated with large dams, not to mention the enormous construction and maintenance costs. For instance: (1) large dams and the associated storage/distribution structures (e.g. diversions, canals) have severely fragmented about 60% of the world's 227 largest rivers, leading to degradation of ecosystems in many cases; and (2) dam construction has caused the displacement of an estimated 40–80 million people from their homes and led to negative economic, social, and cultural consequences at various levels.

The enormity of both the positive and the negative effects of large dams has led to serious debates on the future of such dams. There is also noticeable antagonisms between 'pro-dam' and 'anti-dam' groups. On the one hand, the 'pro-dam' group is strengthened by the growing economic capacity of a number of individual developing nations (e.g. China, India) and to construct large dams for themselves as well as to support dam construction in other countries, without dependence on global funding agencies (e.g. World Bank) as it was during the last century. The 'anti-dam' group, on the other hand, is strengthened both by the far more stringent conditions imposed by global funding agencies in providing financial support for new dam projects and by its own ability to more easily attract global attention for its cause through the ever-improving sophistication in print, visual, and social media. These largely extreme views make a 'fair and balanced' dialog on the role of dams in the development of our societies increasingly hard to achieve.

The present study attempts to provide an unbiased account of the future of dam development around the world, with particular reference to the developing world. The study first argues that construction of large dams will most likely (have to) continue in the developing world for the foreseeable future, if our 'business as usual' approach of excessive water withdrawal, excessive water consumption, inadequate water use efficiency measures, and other deficiencies continues. The study then discusses, through examples, the success as well as failure stories of large dams (and other large-scale water infrastructure projects), including those that have been constructed on transboundary rivers. The general and specific impacts of the World Commission on Dams' Report published in 2000 (*Dams and Development: A New Framework for Decision Making*) on the construction of large dams are also discussed. Finally, the options and challenges in the future planning and management of our water resources, with or without the construction of new dams, are also highlighted (e.g. increasing the size of existing dams, retrofitting environmental flow-related infrastructure, availability or non-availability of suitable dam sites in certain regions/countries where water storage is most needed).

Keywords: *Water management, large dams, transboundary waters, World Commission on Dams*

Knowledge representation using Bayesian Networks and Ontologies

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Abstract: Models are often highly complex incorporating different processes, parameters, scenarios and subjects, and thereby producing different outcome endpoints. The first recommended model development step is the construction of a conceptual model, thereby specifying and defining the processes and relationships to be covered by the model. However, model results are also often highly complex, being fractionalized or simply numerous in quantity, leading to difficulties in representation, communication and interpretation of results. We explore the use of two existing tools and their possible use in knowledge representation and visualization; Bayesian Networks using *Netica* and ontologies using *Protégé*. While visually speaking, both techniques represent knowledge or concepts through network associations between nodes, the information that underlies these representations is vastly different. Bayesian Networks capture relationships using statistical probabilities, whereas ontologies represent structured formalization of relationships.

We explore the use of these two approaches in a novel problem space by representing the modelled outcomes of changed river flow regimes in the MDB to different water development and predicted climate change scenarios and the impact on meeting the watering requirements on the wetland indicator sites in the Southern Murray-Darling Basin. Evaluation of the environmental requirements of wetland indicator sites which are met under different CSIRO Sustainable Yields river flow scenarios representing 109 years of modeled river flows is carried out. As expected, the outcomes of modeling the watering requirements of the wetland sites under different river flow scenarios vary by the scenario, the site and the specific environmental requirement, where watering requirements for the wetland indicator sites are met most of the time under the 'without development' scenario, and only a fraction of the time (4.17%) under the baseline scenario, and less (2.08%) under dry climate scenarios. To represent the outcomes of the river flow scenarios, we present Bayesian Networks, which represent outcomes as a proportion of years where a set of environmental requirements are met, and use utility nodes to display how much additional water is required to meet site-based environmental requirements. We do this for individual wetlands and aggregate outcomes to represent asset requirements in the whole of the southern Murray Darling Basin. Likewise for the approach using ontologies, we formalize a multi-inheritance hierarchy to enable interactive representation of outcomes as defined by different criteria within the model, for example by sites, scenarios, outcomes, or watering requirements. With the ontology approach, this allows representing the outcomes from different positions within the model and observing the derived associations between individual objects based upon the relationships within the ontology model, for example the individual outcomes of a specific flow scenario on a specific wetland indicator site can be represented.

Utilizing the functionality of both Bayesian Networks and ontologies in representation of model outcomes enables a deeper exploration of the underlying model data, enabling interactivity, interrogation and specific queries to be made compared to more traditional representation techniques. Ontologies provide a useful means for exploring individual relationships and associations within the data resulting through the taxonomical data structure, while Bayesian Networks enable exploring the range of specific outcomes from the different dimensions of the data. We discuss the use of Bayesian Networks and ontologies to represent this knowledge in a structured, visual and interactive manner.

Keywords: *Murray-Darling Basin, wetlands, climate change, flow scenarios.*

Using Bayesian networks to advise NRM agencies how to influence the adoption of water use efficiency practices by groundwater license holders

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Abstract: Many new agricultural practices need to be modified if they are going to be sustainable into the future, and this requires adoption by rural landholders. Adoption is a complex process and is typically different for different practices, landholders and contexts. However, it is possible to identify factors that are influential and amenable to influence by natural resource management agencies, and those that are less amenable, but which need to be considered for effective engagement. In this paper we develop a Bayesian network model to explore the influences on the adoption of a set of water efficient management practices, in response to climate change and water entitlement policy, in the Namoi Catchment, an irrigation region of New South Wales, Australia (Figure 1). The management practices included are spray irrigation, soil moisture mapping and modification of flood irrigation methods, measuring dam evaporation and deepening dams, buying water on the temporary or permanent water markets, and changing the crop type and rotation frequencies. A survey of groundwater license holders gathered the data that form the basis of the model (Sharp and Curtis, 2012). Through statistical analysis, those researchers identified a set of variables (from values and beliefs, to property characteristics) that are correlated to the uptake of these practices. The Bayesian network is used to explore the causal relationships between these, and then prioritise which factors have the most influence over adoption.

Of the management practices included, groundwater license holders' were most likely to adopt changing crop types and rotation frequency, and least likely to buy water on the temporary or permanent markets. This is most likely to be a reflection of the variability in the financial cost, simplicity and perceived level of risk in adopting these practices. A key influence in the level of uptake of the various management practices was the type of license holder, whereby those who were More Committed to the Farming Business (MCFB) were more likely to adopt the management practices discussed here, compared to those who were More Committed to Environmental Sustainability (MCES). However, these characteristics are inherent, rather than easily changed. The real value of this research is in suggesting more effective ways to engage these license holders, which included through their industry groups (e.g. short courses) and by appeals to the importance of long-term community and business viability.

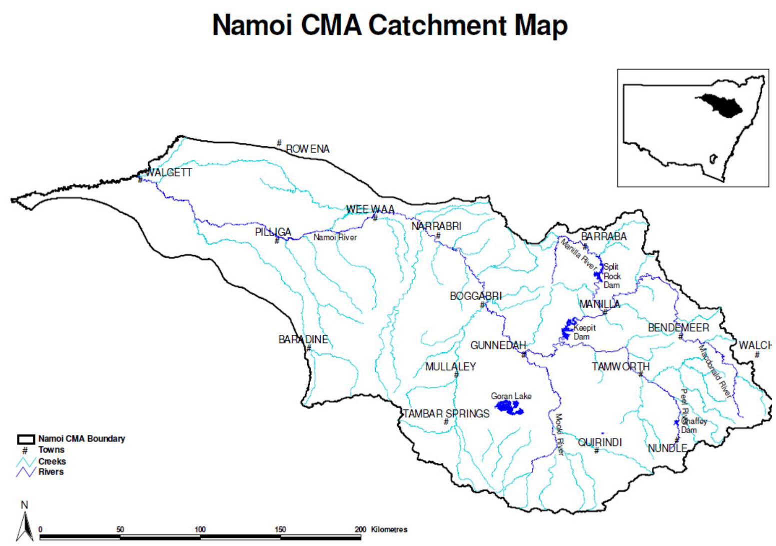

Figure 1 The Namoi CMA catchment map (source: Namoi Catchment Management Authority, http://www.namoi.cma.nsw.gov.au/1namoi_catchment_map_feb06.pdf)

Keywords: *Groundwater, Bayesian network, Adoption*

GCM uncertainty and reservoir storage estimation: A case study of the Warragamba catchment in Australia

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Abstract: Climate change is anticipated to have enormous impacts on our water resources. Whether or not the existing storage capacity of reservoirs is sufficient to meet the future water demands is a question of great interest to water managers and policy makers. Among other factors, uncertainties in GCM projections make accurate estimation of future water availability and reservoir storage requirements extremely complicated. The present study proposes a new method to quantify the uncertainties (or standard errors) of GCM projections and their influence on the estimation of reservoir storage.

Reliable quantification of GCM uncertainties requires utilization of many ensemble runs for each model and emission scenario. However, the climate modeling groups around the world produce only a few ensemble runs for each scenario. Using these limited number of ensemble runs, this study presents a method to quantify GCM uncertainty that varies with space and time as a function of the GCM being assessed. Then, using GCM projection and estimated associated uncertainty, new data series are generated assuming an additive error model which are used to ascertain effects of GCM uncertainties in impact assessment studies. The analysis involves the following important steps: First, standard errors of bias-corrected GCM projections are estimated using multiple model, scenario and ensemble runs conditional on each percentile. Second, assuming an additive error model, several realizations are generated by randomly sampling from normal distribution. Finally, the generated realizations are applied to evaluate impacts of climate change on reservoir storage estimation and establish its associated uncertainty.

The proposed method is applied to quantify uncertainties in rainfall and temperature projections obtained from six GCMs, three emission scenarios and three ensemble runs after correcting biases using the Nested Bias Correction (NBC). Then, thousands of rainfall and temperature realizations are generated using an additive error model for selected GCM and scenario projection. The temperature data are used to estimate evaporation realizations which are then used as input (together with rainfall) to rainfall-runoff model for estimating streamflow. Finally, the streamflow realizations are used to quantify reservoir storage requirements with its associated uncertainties using behavior analysis.

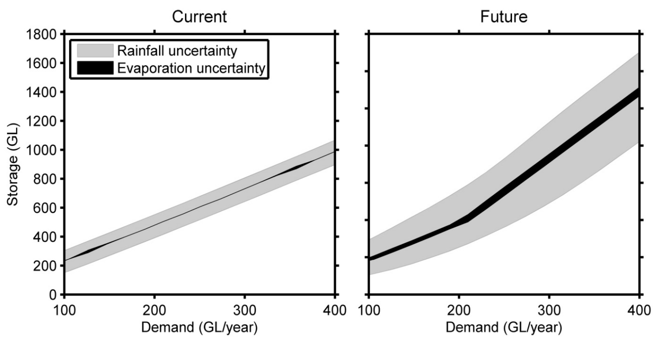

Figure 1: Storage uncertainty originating from rainfall and evaporation for current (1960 to 1999) and future (2001 to 2099) periods for different demand levels.

The results at the Warragamba dam in Australia suggest that GCM uncertainties will be significantly large for the future period than that for the historical period for both rainfall and temperature at different demand levels (Figure 1). Further, comparison of effects of rainfall and evaporation uncertainty suggests that reservoir storage uncertainty is introduced mainly from rainfall, rather than evaporation (Figure 1).

Keywords: *Global Climate Model (GCM), Uncertainty, Water resource assessment, Reservoir storage estimation, Rainfall generation*

Assessing Freshwater Availability in Africa under the Current and Future Climate with Focus on Drought and Water Scarcity

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Abstract: Droughts can have devastating effects on water supply, crop production, food security and many other aspects of human livelihood. The impact is particularly severe in Africa where subsistence farming dominates the food production and where political, social and economic systems are often inadequately prepared to cope with disasters. The recurrence of droughts in the past decades has triggered many famines in the continent. The severity of droughts and their impacts is projected to increase as a consequence of climate change. By applying a semi-distributed hydrological model SWAT (Soil and Water Assessment Tool), this study estimates the different freshwater components (i.e., green and blue water) for the whole African continent at the subbasin level. The spatial and temporal distributions of water resources are assessed. The presented model is then used to project the water resources availability under the future climate change in Africa for the period 2020-2040. Particular attention is made to the dry periods and their implications for water supply and food production. The simulation under the current climate shows that on a continental and annual basis, Africa has abundant water resources but the problem is the large spatial and temporal variability within and between African countries and river basins. The simulation of the impact of the future climate change on water resources is conducted with the projected climate data from 5 global circulation models (GCMs) under the four IPCC emission scenarios. The projected climate data are fed into the SWAT model calibrated under the current climate situation. The results show that for Africa as a whole, the mean total quantity of water resources is likely to increase. For individual subbasins and countries, variations are substantial. Although uncertainties are high in the simulated results, it is found that in many regions/countries, most of the climate scenarios projected the same direction of changes in water resources, suggesting a relatively high confidence in the projections. The assessment of the number of dry days and the frequency of their occurrences suggests an increase in the drought events and their duration in the future. This poses additional challenge to the agriculture in dry regions where water shortage is already severe while irrigation is expected to become more important to stabilize and increase food production.

Keywords: *SWAT, water resources, drought, prediction uncertainty, climate change, Africa*

Surface water modelling in data sparse and varied climate regions for Bioregional Assessments

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Abstract: Coal seam gas (CSG) extraction and coal mining have adverse impacts on water resources in many regions of the world. In Australia, Bioregional Assessments (BA) are undertaken to assess potential impacts of CSG and coal mining development activities on the quality and quantity of water resources so that decisions on future developments are based on improved knowledge. The six bioregions included in the current priority list include areas from varied climatic and geomorphological regions ranging from south east Australia (Lower Gippsland) to northern subtropics (Clarence-Moreton) to arid and semi arid regions (Lake Eyre). Since the surface hydrological processes in these areas vary, modelling requirements of each of these regions will be assessed individually.

While much of the proposed development will affect underground connectivity, water bodies on the surface will be most impacted. Water brought to the surface and treated can be re-injected into underground aquifers or disposed into river systems. Since the extraction of groundwater and the surplus water generated from these activities affect water-dependent assets and receptors located at the ground surface, surface water modelling and assessment is needed to assess these impacts. The modelling and analysis are carried out to assess the impact of excess water on the duration, quantity, frequency and quality of surface water. Changes in the flow regime of rivers due to the changes in connectivity between surface and groundwater are also investigated. To assess the cumulative impacts of CSG and coal mining together with other anthropogenic activities, a spatially explicit model which accounts for current water sector allocations and extractions will be used.

These models will describe current surface water availability and use, and river flow characteristics against which the impact of CSG and coal mine developments can be assessed. The model development and calibration will need to be tailored to address issues specific to each bioregion, which may include (i) flow metrics that influence receptors and assets; (ii) connectivity between surface water and groundwater, and (iii) potential/likely impact of CSG and coal mine developments including disposal of mined water. A multi-criteria and multi-objective calibration approach will be taken to deal with sparse data to utilise information contained within each available data type including the use of qualitative ("soft") information.

The modelling will be carried out by implementing progressive complexity into the model for meaningful representation of the underlying processes and to avoid over parameterisation. The dominant hydrological processes in each bioregion will be identified and modelled using different causative variables. It is envisaged that the above approach will help better understand and simulate the hydrological behaviours in all bioregions.

Keywords: *Coal seam gas, Coal mine, Surface water modelling, Bioregional assessment*

How adequately do gauged tributaries represent the hydrological behaviour of ungauged tributaries in modelling large regulated catchments?

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Abstract: The issue of how adequately gauged, unregulated tributaries represent the hydrological behaviour of ungauged, unregulated tributaries is rarely considered within the context of a single large regulated catchment. We show that in a catchment where the gauging of tributaries is biased towards perennial streams, this bias can result in overestimations of the water balance. The Broken River of south-eastern Australia is regulated and two gauged, unregulated tributaries comprise 49% of the catchment area downstream of the main storage. Both of these tributaries are largely perennial but short-term monitoring of other unregulated tributaries indicates that most of the remaining catchment downstream of the storage have intermittent to ephemeral flow regimes. Deterministic rainfall-runoff model parameters derived from calibration of the perennial tributaries were applied to ungauged intermittent tributaries and found to over-predict runoff, particularly during the low flow phase. Model performance was assessed in the ungauged tributaries using relatively short records (<18 months) of discharge data collected during a field campaign. The application of a probabilistic modelling approach (Generalised Likelihood Uncertainty Estimation, GLUE) to the gauged tributaries defined sets of behavioural model parameters with the median set better able to simulate the flow regime of the ungauged tributaries. The application of the GLUE approach to directly model data from the short record length of the ungauged tributaries required the development of "soft" model assessment criteria to identify behavioural datasets. The latter results showed some improvements in comparison to transferring behavioural datasets from gauged to ungauged tributaries but with wide ranges of uncertainty.

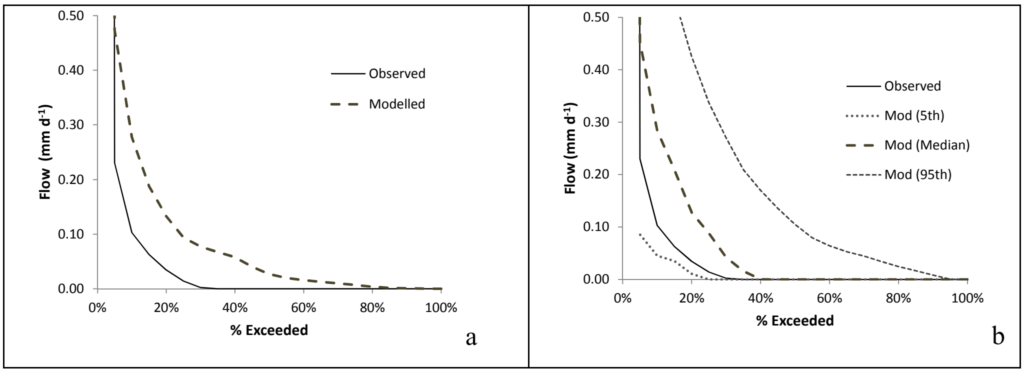

Figure. Flow duration curves for a previously ungauged, intermittent tributary showing observed versus modelled results from deterministic modelling (a) and probabilistic GLUE modelling (b).

Keywords: *Perennial, intermittent, flow regime, Generalised Likelihood Uncertainty Estimation*

Potential improvements to the Australian Water Resources Assessment system landscape (AWRA-L) model

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Abstract: The Australian Water Resources Assessment system landscape model (AWRA-L), is being developed by CSIRO and the Bureau of Meteorology with the intention of providing robust estimates of water yield (runoff and baseflow), evapotranspiration, soil moisture, and aquifer recharge across Australia, specifically for retrospective Water Resource Assessment and National Water Account purposes. This 0.05° (~5km) gridded soil and groundwater balance model is undergoing continual conceptual and parameter estimation development, to reduce the uncertainty and error in the water balance estimates. Significant improvements in the model performance have been achieved to date from the initially parameterised AWRA-L v0.5, yet key areas of weaker performance remain.

This paper identifies areas where AWRA-L v3.0 can be improved when compared to standard and/or simpler models, it provides explanation for the current performance and suggests model improvements. AWRA-L results are compared to other standard rainfall runoff models (GR4J, Sacramento) and the newly developed SpringSIM model. The models are calibrated to streamflow for a set of 305 calibration catchments across Australia, and then validated in 304 additional catchments using nearest-neighbour calibration catchment as parameter set donor (split-sample catchment sampling to test performance in ungauged catchments) as well as using the donor catchment with a minimum separation distance of 50 km, or 200 km (testing the influence of distance on validation performance).

AWRA-L performs adequately using global calibration in the calibration catchments (Figure 1 shows model calibration *F* metric and bias *B*), but the results are inferior to locally calibrated models. However, the AWRA-L local calibration results, while improving on the globally calibrated results in calibration catchments, showed a markedly lower performance than the other models. Encouragingly the AWRA-L global calibration approach resulted in the least bias in validation catchments which confirmed its applicability continent wide when ungauged catchments are likely to be frequently more than 50km from the nearest gauged catchment. Furthermore, AWRA-L performed relatively well when distance was taken into consideration in validation. SpringSIM performed best in calibration, but poorest in validation.

Several areas of potential improvement in AWRA-L relate to spatialisation of properties controlling overland flow generation, streamflow routing, baseflow generation, and soil drainage. It was also found that AWRA-L could be improved structurally if mechanisms to "lose" water by means of an outlet threshold or to increase outflow by means of an interflow generation process were available. It may also be possible to improve results by ensuring that starting soil moisture states were realistic in validation.

Keywords: *AWRA, SpringSIM, Sacramento, GR4J, Rainfall-runoff modeling*

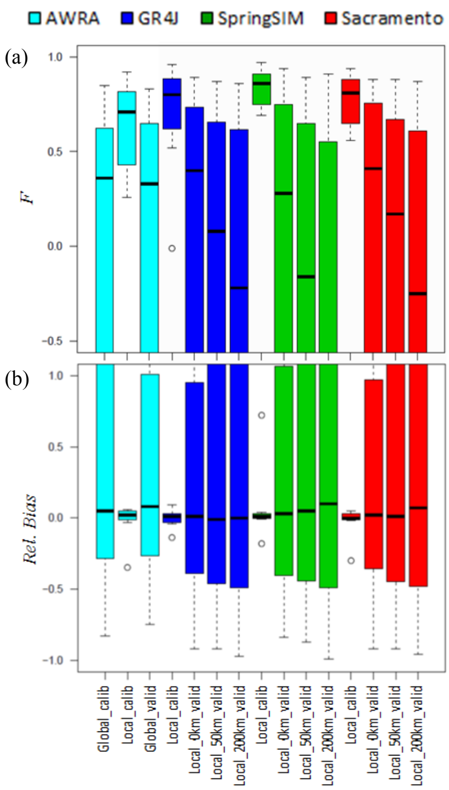

Figure 1. Calibration statistics for landscape water balance models AWRA-L, GR4J, SpringSIM and Sacramento (a) F calibration metric for streamflow and (b) bias in calibration of streamflow. For AWRA-L, results shown are for global calibration, local calibration and application of global parameters to validation catchments, For GR4J, SpringSIM and Sacramento: results are shown for calibration to 305 catchments (Local-calib) and validation in 304 catchments using 0 km, 50 km or 200 km minimum separation distance to donor catchment (Local_valid)

EXTENDED ABSTRACT ONLY

Bayesian Analysis Diagnostics: Diagnosing Predictive and Parameter Uncertainty for Hydrological Models

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Abstract: All scientific and statistical analysis, particularly in natural sciences, is based on approximations and assumptions. For example, the calibration of hydrological models using approaches such as Nash-Sutcliffe efficiency and/or simple least squares (SLS) objective functions may appear to be "assumption-free". However, this is a naïve point of view, as SLS assumes that the model residuals (residuals=observed-predictions) are independent, homoscedastic and Gaussian. If these assumptions are poor, parameter inference and model predictions will be correspondingly poor. An essential step in model development is therefore to verify the assumptions and approximations made in the modeling process. Diagnostics play a key role in verifying modeling assumptions. An important advantage of the formal Bayesian approach is that the modeler is required to make the assumptions explicit. Specialized diagnostics can then be developed and applied to test and verify their assumptions.

This paper presents a suite of statistical and modeling diagnostics that can be used by environmental modelers to test their modeling calibration assumptions and diagnose model deficiencies.

Three major types of diagnostics are presented:

- Residual Diagnostics

Residual diagnostics are used to test whether the assumptions of the residual error model within the likelihood function are compatible with the data. This includes testing for statistical independence, homoscedasticity, unbiasedness, Gaussianity and any distributional assumptions.

- Parameter Uncertainty and MCMC Diagnostics

An important part of Bayesian analysis is assess parameter uncertainty. Markov Chain Monte Carlo (MCMC) methods are a powerful numerical tool for estimating these uncertainties. Diagnostics based on posterior parameter distributions can be used to assess parameter identifiability, interactions and correlations. This provides a very useful tool for detecting and remedying model deficiencies. In addition, numerical diagnostics are provided to test the convergence of the MCMC sampling chains.

- Diagnostics for Probabilistic Predictions

Quantifying predictive uncertainty is becoming a standard part of the modeling process. However, simply providing probability limits on the predictions provides little information on the reliability of these estimates. A series of methods are presented to verify and quantify predictive reliability, resolution and accuracy.

A series of hydrological modeling case studies are used to demonstrate the use of these diagnostics for testing statistical and modeling assumptions and diagnosing model deficiencies. Guidance is given on the interpretation of these diagnostics. The practical implications of poor modeling assumptions is highlighted. Recommendations are provided on the general methodologies for improving the modeling assumptions and reducing modeling deficiencies. The suite of diagnostics is available as an R package, enabling modelers to apply them to their own model development and application endeavours.

Keywords: *Model Calibration, Parameter Uncertainty, Predictive Uncertainty, Diagnostics*

The Australian Water Resource Assessment Modelling System (AWRA)

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Abstract: The Australian Water Resource Assessment (AWRA) modelling system has been in development since 2008 to enable the Bureau of Meteorology to meet its legislated role in providing an annual National Water Account and a regular Australian Water Resource Assessment Report. The system uses available observations and an integrated landscape-groundwater-river water balance model to estimate the stores and fluxes of the water balance required for reporting. AWRA constitutes a unique example of implementing a coupled landscape, groundwater and regulated river system model at a continental scale and rolled out at high priority regions (National Water Account (NWA) regions).

The results for AWRA-L (landscape) implementation across 607 gauged catchments show that in both calibration and validation, the model typically provides streamflow predictions that are similar to those from other widely used conceptual hydrological models. The AWRA-R (river) model includes newly developed components for floodplain inundation modelling, accounting for irrigation diversions and groundwater surface water interactions. The results show that the model performs extremely well in majority of the modelling regions and it provides all the water fluxes and stores required for NWA.

The software architecture developed as part of AWRA integrates the individual components in a seamless manner with transfer of fluxes between the components at a daily time step for operational implementation. The system is fully functional on the Bureau's operating system and used for supporting the production of AWRA and NWA reports. The Bureau has used the AWRA modelling system to undertake water resource assessments across the country and already published one Water Resource Assessment (2010) and two National Water Accounts (2010, 2011). There has been a steady and continuous improvement in the AWRA model performance and the Bureau is currently undertaking the next round of Water Resource Assessments (2012) and a National Water Account (2012) using the current version of the AWRA system. It is anticipated that what-if scenario modelling and forecasting water resource availability will eventually come into scope in the next three years when the retrospective components of the system are fully implemented and operating efficiently and effectively.

Keywords: *AWRA, water resource assessment, landscape modelling, surface water – groundwater interactions, river system modelling*

Comparison of land-cover change and climate variability impacts on runoff using hydrological modelling and sensitivity-based approaches

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Abstract: There are numerous studies reported in literature which investigate the impacts of land use/land cover change and climate change on catchment water availability and there is sufficient evidence that afforestation can reduce streamflow substantially. The most commonly used methods for estimating impacts of plantations on water availability are catchment experiment method, statistical analysis method and the hydrological modelling method. Most of the studies reported in literature normally use either one of the sensitivity-based approach or a hydrological model with few actually comparing the impact results from these different approaches. This paper investigates the impacts of increase or decrease in plantations and climate variability on streamflow using two approaches: the sensitivity-based approach (seven methods) and the hydrological modelling approach (two models) for three medium sized catchments in Australia. The results from the different methods show that both plantation expansion/reduction and climatic differences can have major effects on catchment streamflow.

There is a small variability in the reduction or increase in streamflow estimated by the nine methods. The results from hydrological modelling are compared to those from the sensitivity-based methods. For all the three catchments, when compared to the hydrological modelling results, the Budyko based approaches overestimate the reductions in streamflow due to increase in plantations and underestimate the streamflow reductions due to drier climate. The results from the non-parametric approach are similar to those from hydrological modelling for the Crawford River and Darlot Creek catchments but the non-parametric approach underestimates the streamflow reductions due to increase in plantations and overestimates the streamflow reductions due to drier climate for the Tinana Creek catchment. When comparing the results for reduction in plantations for the Crawford River catchment, the Xinanjiang hydrological model underestimates the increase in streamflow due to reduction in plantations and overestimates the streamflow increase due to wetter climate when compared to the results from the other eight approaches. For the Darlot Creek catchment, the results from all the nine methods are similar and for the Tinana Creek catchment, the non-parametric approach underestimates the increase in streamflow due to reduction in plantations and overestimates the streamflow increase due to wetter climate when compared to the results from the other eight methods.

The results from this study show that the estimates of plantation impacts from the dynamic hydrological models are similar to those from the commonly used sensitivity-based approaches. The sensitivity-based approaches are only applicable where long term data sets are available and they only provide results at a mean annual time scale. The hydrological models simulate plantation impacted streamflow time series and so they can be used to estimate the relative contributions of land cover changes and climate change/variability at a daily, monthly or annual time-step. The outputs from the hydrological models can also be used to investigate the impacts of plantation expansion or reduction and climate change/variability on different runoff characteristics.

Keywords: *Hydrological modelling, sensitivity-based approach, Runoff, Plantations, Afforestation, Climate change*

EXTENDED ABSTRACT ONLY

Influence of regionalisation distance on nearest-neighbour regionalisation

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Abstract: Since most catchment models depend upon calibration against observed streamflow, some form of regionalisation is usually required to facilitate estimation of streamflow for ungauged catchments. Perhaps the most common form of regionalisation is that based on spatial proximity. The basic premise of proximal, or nearest-neighbour, regionalisation is that streamflow in an ungauged catchment can be estimated by adopting the calibrated model parameters from the nearest gauged catchment and using them in conjunction with local climatic and other input. There is an underlying assumption in nearest-neighbour regionalisation that nearby catchments are more likely than distant catchments to share common climates, soils, land covers and land forms, and are therefore more likely to exhibit similar hydrological behaviour. This paper assesses the degree to which regionalisation distance affects the quality of nearest-neighbour regionalisations. Five catchment models are calibrated on 232 catchments in southeastern Australia. Each of the 232 resulting parameter sets can potentially be applied in regionalisation to any of the 231 remaining catchments. This yields a large range of potential regionalisation distances. The effect of regionalisation distance on validation performance can be analysed by selecting as donor-target pairs, catchments whose separation exceeds some arbitrary threshold. The resulting prediction performances for one model are shown in Figure 1, and are typical of results for other models, for other performance metrics and for other parts of Australia. There is a clear degradation in performance as the threshold distance increases from 0 km up to 150 km. For distances of 150 km and above, the differences between the curves are less pronounced. A more detailed response may be obtained by using a much larger set of regionalisation distances with smaller (5 km) step sizes (Figure 2). In general, the behaviours of the five models in Figure 2 are broadly similar. When using progressively larger regionalisation distances up to about 150 km, model performance degrades significantly, but beyond about 150 km, model performance appears to be independent of regionalisation distance. It is postulated that a distance of about 150 km represents a characteristic scale of hydrologic similarity for Australian catchments. The rapid initial degradation of prediction performance with regionalisation distance also has important implications for globally calibrated models—models where a single parameter set is applied to a large range of gauged and ungauged catchments. In general, the validation performance of such models is independent of catchment separation, and while their performance may be slightly worse than that of locally-calibrated models validated using nearest neighbour parameters, they can significantly surpass the latter when nearest-neighbour regionalisation distances increase. This suggests that the widespread convention for validating locally-calibrated models using nearest donors only, could, in some circumstances, lead to unrealistically high expectations of model performance in ungauged catchments.

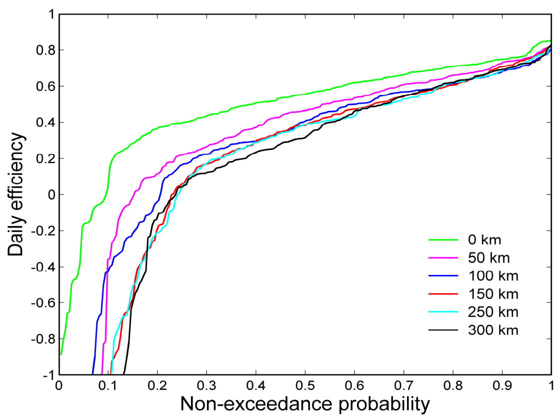

Figure 1. Cumulative frequency of daily efficiency of SMAR-G in 232 catchments in southeastern Australia for proximal validation at several minimum regionalisation distances.

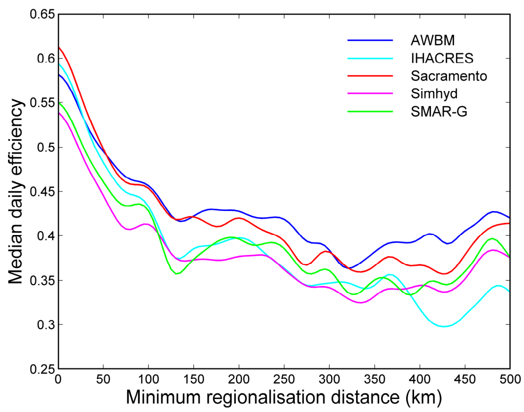

Figure 2. Relationship between minimum regionalisation distance and median prediction efficiency for five models applied to the same catchments as in Figure 1. A low-frequency smoother has been applied to the raw data.

Keywords: *Streamflow modelling, regionalisation, prediction in ungauged catchments*

Catchment grouping and regional calibration for predictions in ungauged basins

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Abstract: Runoff prediction in ungauged regions remains a challenging task in hydrology (Sivapalan et al. 2003). The process of finding suitable parameter values to model runoff in ungauged catchments, by inferring and learning from model calibrations in gauged catchments, is generally referred to as 'regionalisation'. An increasing number of studies now use a regional calibration approach (Vogel 2005; Vaze et al. 2011a; 2013). The regional calibration finds one set of parameter values to represent the entire 'hydrologically similar' region rather than considering each catchment independently. In the regional calibration, the model parameters are optimised to produce an overall best simulation for all the gauged catchments within the region. Vaze et al. (2011a) suggested that the regional calibration has capability to accommodate extra local information by, e.g., using different sets of parameters to represent catchments with different vegetation or land use types across the target region. Vaze et al. (2013) also showed that the regional calibration approach has an advantage as it can incorporate information from new data sources, like remotely sensed vegetation, evapotranspiration and soil moisture, to improve model characterisation, reanalysis and predictions.

While applying a regional calibration to a large region such as south-eastern Australia, all catchments cannot be assumed to have similar hydrological behaviour, and hence a sub-grouping approach based on differences in physical catchment characteristics is required. This can be facilitated by using remote sensing data which provides a complete coverage of a range of catchment characteristics. There are many catchment characteristics that have been used in past studies to measure the hydrologic similarities between catchments for model regionalisation (Oudin et al. 2008; Zhang and Chiew, 2009). But there still remains a question about which catchment characteristics are more informative to measure the hydrological similarity for hydrological response in a specified region.

This study attempts to answer this question by undertaking modeling experiments by sub-grouping catchments based on three physical catchment and climate characteristics – the fraction of vegetation coverage (fPAR), aridity index (AI) and rainfall distribution over seasons (Seasonality). The hydrological model is regionally calibrated for each of the sub-groups and the calibrated model parameters are used to simulate runoff over different independent periods (model validation). The results are compared with those obtained from using sub-groups of randomly selected catchments. The results have also been compared against classic regionalisation based on spatial proximity, where all the 196 catchments are calibrated individually and the calibrated parameter set from the geographically closest catchment is used to simulate streamflow for 'ungauged' catchments.The experiments are carried out using data from 196 unregulated and unimpaired medium sized catchments (50-2000 km^2) (Vaze et al., 2010) across south-eastern Australia for the period 2000-2008. The hydrological model used in this study is the 4-parameter GR4J Model (Perrin et al. 2003).

The results show that the classic local calibration and validation approach perform best, and the regional calibration against the whole catchment set (only one parameter set for all catchments) gives the worst results. The results also show that daily runoff predictions from the catchment characteristics-based sub-grouping approaches perform substantially better than that from random sub-grouping. The results also indicate that predictions from sub-grouping based on both aridity index and the seasonal rainfall distribution are able to offer comparable performance to local regionalisation based on spatial proximity. Although the standards for sub-grouping and the number of sub-groups may be subjective, the results suggest that regional calibration with catchments sub-grouping based on catchment physical properties has potential to improve hydrological predictions over large regions.

Keywords: *Rainfall-runoff modelling, regional calibration, regionalization, catchment characteristics*

EXTENDED ABSTRACT ONLY

Hydrologic signatures for runoff prediction in ungauged catchments

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Abstract: Hydrologic signatures include a set of hydrological indices or a time series of the response behaviour of a catchment at different time steps. They can be runoff coefficient, zero flow ratio, a measure of runoff seasonality, flow duration curves and daily time series of runoff. Hydrologists need to understand and predict hydrological behaviour under different climate or catchment conditions. Hydrologic signatures can be used for water resource management, catchment classification, and predicting runoff time series.

This study investigates nearest neighbour and three spatial interpolation approaches for predicting six hydrologic signatures in ungauged catchments in southeastern Australia. The three spatial approaches include inverse distance weighting (IDW), kriging and spline spatial interpolation. The six hydrologic signatures are runoff coefficient, zero flow ratio, mean of log-transformed daily runoff, standard deviation of log-transformed daily runoff, runoff seasonality ratio at the 95th percentile and concavity index. The choice of the six signatures is based on whether they could represent high-level aggregation of streamflow and other salient flow characteristics and whether they could be used to derive a flow duration curve. A total of 228 unregulated catchments are used for the study, with half the catchments randomly selected to develop the hydrologic signatures and the other half used to evaluate the performance of the nearest neighbour and the three spatial interpolation approaches to predict the hydrologic signatures.

Compared to the nearest neighbor approach, IDW and kriging noticeably improve estimates of the six signatures. This is because they put higher weights on geographically nearer donors and lower weights on more distant donors. The IDW approach improved the Nash-Sutcliffe Efficiency (NSE) values for runoff coefficient, mean of log-transformed daily flow, zero flow ratio, standard deviation of log-transformed daily flow, runoff seasonality ratio, and concavity index by 0.08, 0.06, 0.35, 0.35, 0.25, and 0.21, respectively. The kriging approach gives poorer estimates of standard deviation of log-transformed daily flow (the NSE value lower by 0.08), but improves the NSE values for runoff coefficient, zero flow ratio, standard deviation of log-transformed daily flow, runoff seasonality ratio, and concavity index by 0.09, 0.21, 0.25, 0.29, and 0.07, respectively. The spline approach performs more poorly than the nearest neighbor approach for most of the signatures, except for zero flow ratio and runoff seasonality ratio.

Comparison of the three spatial interpolation methods show that the IDW method improves the performance for runoff coefficient, mean of log-transformed daily flow, zero flow ratio, standard deviation of log-transformed daily flow, runoff seasonality ratio , and concavity index (NSE increased by 0.40, 0.18, 0.27, 0.69, 0.13, and 0.76, respectively, when compared to the spline method. A similar improvement is seen using the kriging method (NSE increased by 0.41, 0.04, 0.13, 0.59, 0.16, and 0.62, respectively). The NSE values for runoff coefficient and runoff seasonality ratio obtained from the IDW method are similar to those obtained from the kriging method, but the NSE values for other four indices obtained by the IDW method are noticeably better than those obtained by the kriging method.

This study also compares the performance of these methods for predicting a flow duration curve (FDC) in ungauged catchment. The FDC is estimated by a three-parameter approach using zero flow ratio, mean of log-transformed daily runoff, and standard deviation of log-transformed daily runoff. The results for FDC are similar to those for an individual hydrologic signature, indicated by a degrading performance order from IDW to kriging, nearest neighbor, and to spline.

These results suggest that the IDW method is by far the best spatial interpolation method for predicting hydrologic signatures of ungauged catchments. The kriging method is intermediate while the spline method performs worst.

Keywords: *Hydrologic signatures, ungauged catchments, runoff prediction*

Urban development and the water balance: coupling land-use dynamics and the hydrological system

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Abstract: Water resources sustainability is threatened by global population growth and urbanization. Land-use change and increased sealed surfaces have a considerable impact on water resources. To mitigate the impacts of this trend, more research is needed on appropriate modeling strategies and tools. We coupled the spatially-distributed hydrological model WetSpa with a simplified version of land-use change model 'RuimteModel', an advanced version of the MOLAND modeling framework. The Python coded WetSpa has a modular structure; process-based components of the model are developed using an environmental modeling framework prototype. The modular structure enhances flexibility and ease of integration, every physically-based process (such as evapotranspiration, runoff, etc.) is coded in a separate module and these modules exchange user-selected variables during run time through the environmental modeling framework prototype. The user can select which processes will be simulated by the model as well as the spatial and temporal resolution of each module separately, while the framework takes care of the order of calculation and of data exchange. The coupling, developed with the same framework, is bidirectional: (1) land-use maps, outputs of the 'RuimteModel', are used by WetSpa to derive parameters for surface water fluxes, and (2) river discharges, simulated by WetSpa, are converted into flooding zones maps which affect the suitability of new buildup area in the land-use change model. This contribution describes the new modeling approach, the coupling mechanism and the relative influence of urbanization on the hydrological system by mean of a case study.

We applied the coupled models to the Kleine Nete catchment, Belgium. The 'RuimteModel' simulates the land-use dynamics for the Flanders region, Belgium, with a spatial resolution of 100 m and a temporal resolution of 1 year. The WetSpa model has a spatial resolution of 50 m and a temporal resolution of 1 day for the simulation period from 01/01/1995 to 01/01/2013. The environmental modeling framework prototype manages the data exchange and the spatial-temporal re-sampling needed for the coupling of the two domains, land-use dynamics and hydrology. We developed a simple intermediate component to derive flooding maps from the river discharge on basis of a stage-discharge relationship. The time-variant water levels are then converted into a two-dimensional water surface, and the flooded cells are identified when the difference between the water surface and the elevation exceeds a flooding threshold. The flooding zones are converted into suitability maps for urban development by simply assigning a flooded cell as not suitable for housing. Results demonstrate that the bidirectional coupling leads to a reduction of cells classified as urban in the areas susceptible of floods. Modularity is a key feature for hydrological models of urbanized catchments as it allows simple but effective methods to expand the modeling capabilities, such as the assessment of land-use change impact on the hydrological system. The application of the model to the case study provides insights on the relative dependence of the both land-use and hydrological change, which should no longer be considered separately. The method used for deriving flooding and suitability zones can in future research be improved with a more rigorous description of two-dimensional flow processes and a suitability based on damage cost functions.

Keywords: *Urban hydrology, land-use dynamics*

A Scenario Analysis Approach to Distributed Energy System Optimisation

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Abstract: This work presents a scenario analysis approach to the planning and optimisation of distributed energy resource systems (DER). Increasing concern relating to the depletion of fossil fuels and the generation of greenhouse gasses from traditional centralised power generation has led to an increased interest in more sustainable distributed technologies. Carbon emission reduction is particularly pertinent in Australia which currently produces more carbon per person than any other developed country in the word and has set the demanding target of 80% reduction below 2000 emission levels by 2050 (Australian Government, 2008). The primary barrier to the widespread adoption of DER technologies is the long and somewhat uncertain financial return associated with large capital investment. Therefore a need exists to maximise financial return, by selecting appropriate system sizes and technologies for a given load and climate condition. Significant research exists on optimising, planning and evaluating distributed energy systems through mathematical and optimisation models that take into account loads, climate, tariffs and technical performance.

Some examples of DER system optimisation at the planning stage include investigation of optimal investment strategies in decentralized renewable power generation under uncertainty. This research forecasted future prices for DER system technologies in addition to feed in tariffs to determine price intervals at which different generator capacities should be installed. Multi-objective optimisation has also been performed for planning and evaluating distributed energy systems by taking into account both CO_2 emissions and net present value. Researchers have determined the optimal system combination and corresponding financial and environmental performance of DER systems. Optimisation of system sizing and operation has been performed for a wide variety of intermittent and dispatch-able DER generation systems. DER systems have been optimised for given load and climate conditions whilst guaranteeing reliable system operation using a single year of data at hourly intervals.

The above methodologies assume that the key inputs (load profile, feed in tariffs, usage tariffs etc.) are constant throughout the lifetime of the system. Not only is this definitely not the case but many of the inputs will exhibit significant uncertainty over the systems lifespan. For example if the optimisation of a new co-generation facility were to be undertaken then the load magnitude and profile that the facility would service could vary each year depending on the rate and nature of development in the new precinct. Additionally other key variables used in determining the financial (and environmental) performance will vary significantly and unpredictably including feed-in tariffs, usage tariffs, thermal load profiles and gas prices. Hence to account for these uncertainties scenario analysis is used to identify the key drivers for each input variable such as building vacancy, recession, advances in energy saving appliances, behavioural changes, policy changes etc. and therefore develop a number of possible future scenarios. Each future scenario provides different input parameters, each varying over the lifespan of the project. Using these final scenarios optimisation can occur to find the most robust or preferred DER system. This can proceed in multiple ways including finding the scenario-weighted optimal solution or the most robust solution across all scenarios.

This paper presents a proposed framework developed to account for long term variability and uncertainty in DER system optimisation. The objective function, constraints and performance modelling methodology are presented in addition to the implementation of scenario analysis in the final optimisation algorithm.

Keywords: *Distributed energy systems, micro-grid optimisation, scenario analysis*

Does interactive visualisation increase stakeholders' understanding?

A case study of Te Waihora/Lake Ellesmere, Canterbury, New Zealand

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Abstract: Visualisation has been used in a number of natural resource management applications with the aim of enhancing people's personal understanding of issues but little evaluation of the effectiveness of the tools developed has been undertaken. The purpose of this study was to investigate whether interactive visualisation increase stakeholders' personal understanding of lake values using a case study of Te Waihora/Lake Ellesmere, in the South Island of New Zealand.

Te Waihora/Lake Ellesmere is a broad, shallow lake. It is separated from the Pacific Ocean by the long narrow sandy Kaitorete Spit. Its unique position allows for it to be opened to the sea periodically to provide drainage and prevent flooding of surrounding farmlands. There is a lack of agreement among the diverse stakeholders regarding the appropriate levels at which the lake level should be maintained throughout the year.

We describe an interactive visualisation tool (ElleVis) which shows the effects of different lake opening regimes on lake values at Te Waihora/Lake Ellesmere. The tool allows users to input different opening scenarios and visualise the resulting impact on water levels around the lake at various times. It incorporates historical rainfall data from New Zealand's National Institute of Water and Atmospheric Research to deliver a graphical map display, including a summary table with a 'traffic light' status for lake values - birds, fish, farming and other stakeholder interests at different locations around the lake. The interactive nature of the ElleVis tool allows the stakeholders to compare Te Waihora/Lake Ellesmere under different opening scenarios using one interactive tool.

A quasi-experimental design was adopted to measure the knowledge of the participants before and after using the ElleVis tool. Overall, participants' scores were significantly higher ($M = 34.5$, $SD = 6.549$) after using the ElleVis visualisation tool than before ($M=22.5$, $SD = 7.408$) t (13) =5.842, p = .005. Post-study comments from the participants were analysed to see if there were any patterns or differences with participants' experiences or impressions with the use of ElleVis. The results revealed that interactive visualisation can increase the personal understanding of stakeholders with diverse interests. More widely, the findings of this study inform discussions about whether visualisation tools might contribute to the management of "disagreements" in environmental management in situations that involve contested resources or a multiplicity of interests.

Keywords: *Personal understanding, interactive visualisation, simulation, evaluation, visual simulation*

Assessing the ability of infiltration-based WSUD systems to manage channel-forming flow regimes in greenfield catchment developments: A catchment scale investigation

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Abstract: Catchment urbanisation is an inevitable and growing form of land-use change. These land-use changes have profound impact on catchment hydrology by altering the quantity and quality domains of flow characteristics in stream channels resulting in increased flood hazards, degraded aquatic ecosystem health and changed channel geometry. The concept of stormwater source control emerged from the need for managing stormwater in urbanised catchments with the aim of alleviating the detrimental impacts of catchment urbanisation on flow regimes, associated stream geometry and ecosystems health. These source control techniques are called Water Sensitive Urban Design (WSUD) in Australia and are increasingly being endorsed and adopted for managing stormwater in urbanising catchments. Consequently, the hydrologic response in urban and peri-urban catchments will be decided or influenced by the WSUD systems in those catchments in the future.

This paper focuses on assessing the ability of infiltration-based WSUD systems in maintaining channel-forming flow regimes in greenfield catchment developments. The performance evaluation methodology is demonstrated by constructing hydrologic models for natural, urban, and managed (with WSUD) conditions for a selected case study catchment. The US Environmental Protection Agency Storm Water Management Model (SWMM) is used as the modelling tool. WSUD systems were designed based on the use of the flow duration control approach based on continuous simulation of flows. Two urbanisation levels were investigated: 30% and 70% of directly connected impervious area (DCIA) of the catchment in the study.

The system performance was assessed using selected flow indices. The results of the study depicts that urbanisation dramatically change the natural flow regime. Under urbanised conditions of the catchment, magnitude of peak flow was notably increased while low flow was reduced. The increased frequency and duration of channel-forming flow was also evident under catchment urbanisation. The implementation of infiltration-based systems helps to reduce the impact of urbanisation by bringing flow values close to their natural conditions value. The infiltration-based WSUD systems adopted in this study can manage the channel-forming flow magnitude, frequency and duration close to their predevelopment levels. The adopted WSUD systems effectively reduce increased runoff volumes under urban conditions close to natural volumes. The percentage of time that flows exceeded $Q_{1.67}$ increased from the natural value of 0.71% to 1.9% at 30% DCIA scenario and employing bioretention systems in the developed catchment effectively reduced flow frequencies of $Q_{1.67}$ back to 0.63%. The magnitude of $Q_{1.67}$ increased by 586% from the natural catchment value at 30% DCIA and stormwater management using bioretention systems reduced the statistic down to 13% of natural value. The duration of $Q_{1.67}$ flow was increased by 170% from its natural value at 30% DCIA scenario and with the implementation of WSUD systems, $D_{Q1.67}$ reduced up to 11% below its natural value. Similar results were obtained for 70% DCIA scenario. These improvements in streamflow regime would reduce the impact of urbanisation on channel geometry and ecological health.

Keywords: *Catchment modelling, Water Sensitive Urban Design (WSUD), Source Control, Storm Water Management Model (SWMM)*

Adapting Geospatial Business Intelligence for Regional Infrastructure Planning

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Abstract: Business Intelligence (BI) has traditionally been used in organizations as a strategic tool to maximize profit. When coupled with Geographic Information Systems, however, BI can be transformed into a cutting edge decision support system for planning local and regional areas, as we demonstrate in this paper. Local and regional governments often face a major challenge in terms of developing a holistic view upon disjointedly operated utility services in their jurisdictions due to data silos. This limitation has become a serious impediment to infrastructure planning and regional adaptation to changes. Geo-BI provides tools to manage data coming from multiple and disparate sources, and visualize them through online interactive user-interfaces. The SMART Infrastructure Dashboard (SID) is an innovative Geo-BI solution that includes an open-source ETL (Extract, Transform and Load) toolkit to handle various datasets, a spatially-enabled data warehouse hosted in PostgreSQL/PostGIS and proprietary BI software for creating and administering analytical reports and dashboards. SID allows planners and policy makers to analyze the interplay between the use of infrastructure services, demographics and weather parameters across multiple spatial and temporal scales. Furthermore, SID enables planners to run various what-if scenarios related to projected consumption patterns, service vulnerability of utility networks, and transportation demand management. Future research involves enabling the analysis of networks of networks through SID to understand the propagation of cascading failures and benefits in interconnected utility networks.

Keywords: *Geospatial Business Intelligence, Infrastructure, Regional Planning*

Analysis of root-zone soil moisture control on evapotranspiration in two agriculture fields in Australia

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Abstract: Soil moisture content in the root-zone is an important variable in modeling hydrological and biophysical processes and agricultural applications. For example, partitioning of surface energy exchange into the latent and the sensible heat fluxes is affected much by soil water content. Typically surface moisture content has been mapped using the microwave remote sensing techniques at large scales. In addition to the microwave remote sensing, there is a growing interest in mapping high-resolution soil moisture content using remotely sensed thermal signals or evapotranspiration (ET). This new technique is based on the assumption that the evaporative fraction (EF) or the ratio of actual ET to potential ET (AET: PET) is controlled by soil water content available for bare soil evaporation or vegetation transpiration. However, there are a number of environmental and biological factors contributing to EF and AET: PET such as the net radiation, vapor pressure deficit, vegetation biomass and growth stage, *etc*. This work investigates effectiveness of the EF and AET: PET based root-zone soil moisture estimation in the agricultural landscapes. In order to analyze the sensitivity of EF and AET/PET to soil moisture, meteorological and biophysical variables, we use continuous observations of surface reflectance, eddy-covariance ET, profile soil moisture and other meteorological variables collected by tower-based Spectro-Eddy-Covariance (SEC) systems installed in experimental farm sites in Victoria, Australia. Two SEC systems are installed in two rain-fed agricultural fields; wheat, pasture covered with lucerne. Statistical analyses were conducted to identify key contributors to EF and AET: PET, which can be ultimately used to constrain ET-based soil moisture estimation scheme.

The correlation between EF and AET/PET was good throughout the vegetation period with R^2 value 0.83. Therefore, we showed that EF or AET: PET exhibits consistent correlations with soil water available for vegetation in both study sites. The exponential model appears to provide reasonable estimates of EF using soil moisture with R^2 value of 0.78. The model performance was further decreased yielding an R^2 value of 0.52 with inclusion of bare soil conditions. EF vs. soil moisture at surface and root-zone is sensitive to vegetation biomass. For soil moisture 0-8 cm, correlation is higher during bare soil condition while for 0-30 cm, correlation is significantly higher when there is enough biomass. The relation between the EF and soil moisture is strong when ET is water limited and correlation become weak when ET is energy limited. Implications are that, when estimating root-zone soil moisture using EF, we have to consider net radiation and NDVI greater at critical threshold levels and soil depth should be specified properly. Analysis indicates that the net radiation and NDVI are the most important factors, other than soil moisture, that influences the ET versus soil moisture relationship, and the influence varies with season.

Keywords: *Evapotranspiration, Root-zone soil moisture, Thermal infrared remote sensing*

Impact of observation error structure on satellite soil moisture assimilation into a rainfall-runoff model

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Abstract: In the Ensemble Kalman Filter (EnKF) - based data assimilation, the background prediction of a model is updated using observations and relative weights based on the model prediction and observation uncertainties. In practice, both model and observation uncertainties are difficult to quantify thus have been often assumed to be spatially and temporally independent Gaussian random variables. Nevertheless, it has been shown that incorrect assumptions regarding the structure of these errors can degrade the performance of the stochastic data assimilation.

This work investigates the autocorrelation structure of the microwave satellite soil moisture retrievals and explores how assumed observation error structure affects streamflow prediction skill when assimilating these observations into a rainfall-runoff model. An AMSR-E soil moisture product and the Probability Distribution Model (PDM) are used for this purpose.

Satellite soil moisture data is transformed with an exponential filter to make it comparable to the root zone soil moisture state of the model. The exponential filter formulation explicitly incorporates an autocorrelation component in the rescaled observation, however, the error structure of this operator has been treated until now as an independent Gaussian process. In this work, the variance of the rescaled observation error is estimated based on the residuals from the rescaled satellite soil moisture and the calibrated model soil moisture state. Next, the observation error structure is treated as a Gaussian independent process with time-variant variance; a weakly autocorrelated random process (with autocorrelation coefficient of 0.2) and a strongly autocorrelated random process (with autocorrelation coefficient of 0.8). These experiments are compared with a control case which corresponds to the commonly used assumption of Gaussian independent observation error with time-fixed variance.

Model error is represented by perturbing rainfall forcing data and soil moisture state. These perturbations are assumed to represent all forcing and model structural/parameter errors. Error parameters are calibrated by applying two discharge ensemble verification criteria. Assimilation results are compared and the impacts of the observation error structure assumptions are assessed.

The study area is the semi-arid 42,870 km^2 Warrego at Wyandra River catchment, located in Queensland, Australia. This catchment is chosen for its flooding history, along with having geographical and climatological conditions that enable soil moisture satellite retrievals to have higher accuracy than in other areas. These conditions include large area, semi-arid climate and low vegetation cover. Moreover, the catchment is poorly instrumented, thus satellite data provides valuable information.

Results show a consistent improvement of the model forecast accuracy of the control case and in all experiments. However, given that a stochastic assimilation is designed to correct stochastic errors, the systematic errors in model prediction (probably due to the inaccurate forcing data within the catchment) are not addressed by these experiments. The assumed observation error structures tested in the different experiments do not exhibit significant effect in the assimilation results. This case study provides useful insight into the assimilation of satellite soil moisture retrievals in poorly instrumented semi-arid catchments.

Keywords: *Data assimilation, soil moisture, satellite retrievals, rainfall-runoff model, hydrology*

Modelling overbank flood recharge using satellite imagery of flood inundation

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Abstract: Accurate calculation of groundwater sustainable yield requires a reduction in uncertainty in all components of the water balance. In particular, there is a need to better constrain losses from rivers to groundwater and understand surface water – groundwater interactions. Continental and global scale models commonly contain algorithms for river losses to groundwater through the river bed and, in some instances, bank storage processes. They rarely, however, include explicit processes to account for overbank flood recharge (OFR): groundwater recharge from flooding outside of the river channel. Overbank flood recharge is being included in the water budget for the AWRA (Australian Water Resources Assessment) system, linking the river and groundwater components of the model. Overbank flood recharge has previously been calculated as the minimum of three limiting factors – the potential infiltration of flood water overlying a shallow watertable, the capacity of the aquifer to store this infiltrated water, and the capacity of the aquifer to transport the water away from the infiltrating site. In this study, these analytical equations were upscaled to a continental scale using available national soil data and satellite imagery of flood inundation. Data for surface soil clogging layer thickness and hydraulic conductivity were provided by the Australian Soil Resource Information System (ASRIS). Spatial information for on flooding extent was calculated from the open water likelihood (OWL) and flood depth data provided by MODIS satellite imagery. Unexplained flooded cells in the flood inundation data (noise) were reduced in the modelling by using threshold OWL values of 10% and 20% to represent flooding, and by screening out data affected by cloud coverage. Overbank flood recharge maps were produced for seven hydrologically and climatically different Australian catchments: Daly River (NT), the Condamine and Logan Rivers (Qld), the Lachlan and Murrumbidgee Rivers (NSW), and the Campaspe and Loddon Rivers (Vic). OFR modelling was undertaken for the severe floods in eastern Australia that occurred around January 2011, with a modelling period from November 2010 until March 2011. Overbank flood recharge was evident for the Loddon, Campaspe and Condamine catchments, with small volumes of recharge also present for the Lachlan and Murrumbidgee catchments. OFR in the Loddon, Campaspe and Condamine catchments was compared with independent estimates of recharge derived from bore hydrograph responses, calculated using the watertable fluctuation (WTF) method. These comparisons showed a similar spatial distribution of OFR within the catchments and a similar order of magnitude of recharge, with the algorithm slightly under-predicting the recharge compared with the bore hydrograph response. The Loddon catchment was selected for a more detailed comparison between spatially determined OFR, point scale recharge modelling and change in groundwater storage calculated from groundwater maps. Point scale estimates of recharge were modelled using WAVES, a 1-D soil-vegetation-atmosphere-transfer model. Recharge was estimated for Sodosol and Vertosol soils, and annual and perennial pastures, and for scenarios including rainfall only, rainfall and flood recharge, and application of irrigation water. Multivariate kriging with external drift (KED) was used to map watertable surfaces from bore observations before and after the flood event. Again, the algorithm used to model OFR within the AWRA system was found to generate the same order of magnitude of recharge, but slightly under predicted the result. OFR was found to comprise at least 5% of the total recharge in a water budget over the Loddon catchment for the duration of the modelling. The three methods of comparison (point scale recharge calculation, point scale recharge modelling and spatial watertable mapping) were useful for gaining confidence in the modelled OFR values. The algorithms used to model OFR within the AWRA system were found to be appropriate for use at a catchment to continental scale. The study highlighted a need to focus on improvement in continental scale data sets, in particular aquifer specific yield, transmissivity and surface soil characteristics.

Keywords: *Overbank flood recharge, global scale modelling, sustainable groundwater yield, satellite derived flood inundation*

Examining the impact of scale variations on soil moisture downscaling using temporal persistence

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Abstract: Soil moisture estimation is an integral component of operational hydrology including flood forecasting, drought monitoring, catchment management, and groundwater recharge estimation. Typically, soil moisture information is required at variable spatial scales for the above applications. As a result, soil moisture data at one spatial scale are often aggregated to larger areas or disaggregated to smaller areas for a particular application. There is also increasing demand for accurate downscaling of satellite derived data to smaller spatial resolutions. This transition in spatial scale is often fraught with uncertainties because of the high spatio-temporal variability of soil moisture. However, the rank of soil moisture at a particular location in relation to other spatial locations is widely known to be temporally stable at a certain probability. The concept of temporal persistence of soil moisture offers the potential to better estimate soil moisture across spatial scales. The application of temporal persistence for estimation of soil moisture across spatial scales has not been thoroughly investigated in the literature. As a result, this study examines the relationship between the rank stability of soil moisture and physiographic features including vegetation types and soil texture groups. This investigation provides physiographic explanations for temporal persistence of soil moisture, and therefore facilitate soil moisture estimation across scales.

To assess the estimation across scales, soil moisture data for three spatial resolutions of 12-km, 5-km, and 1-km data for the Yanco region in New South Wales, Australia were used. The soil moisture data for the 12-km, 5-km and 1-km resolutions are land surface model estimates obtained from the Joint UK Land Environment Simulator (JULES). The vegetation data set was obtained from the Australian National Dynamic Land Cover Data set (DLCD). The DLCD was generated from a 16-day Enhanced Vegetation Index composite collected at 250-m resolution from Moderate Resolution Imaging Spectro-radiometer (MODIS) for the period from 2000 to 2008. The DLCD has land cover features clustered into 34 ISO classes with descriptions for the structural character of vegetation, ranging from cultivated and managed land covers (crops and pastures) to natural land covers such as closed forest and sparse, open grasslands.

The soil texture data set was derived from the Digital Atlas of Australian Soils which was obtained from the Australian Soil Resource Information System (ASRIS). ASRIS provides a digital map of soil types and their descriptions, typical ranges for soil properties for each soil type, morphology, and physical properties of soil profiles. The soil classification in ASRIS has six main textural groups including sands, sandy loams, loams, clay loams, clay, and light clays. Moreover, the meteorological forcing data including short and long wave incoming radiation, air temperature, precipitation, wind speed, pressure, and specific humidity were obtained from the Australian Community Climate Earth-System Simulator - Australian (ACCESS-A) at hourly time step with approximately 12-km spatial resolution. The ACCESS-A precipitation data set was bias corrected using a 5-km gridded precipitation data from the Australian Water Availability Project (AWAP) data obtained through the Australian Bureau of Meteorology.

The results identified temporally stable locations between the three resolution pairs with a percent relative difference of about 6$\%$ maximum and 0.1$\%$ minimum; indicating that the overall difference for downscaling soil moisture across the three resolution pairs is about 3$\%$ of the original value. It was found that temporal stability of soil moisture can facilitate downscaling of soil moisture across different spatial scales, with improved accuracy for decreasing size of spatial resolution. Soil texture and vegetation land cover do not provide strong indicators to identify temporally stable locations, with vegetation cover having a higher correlation than soil texture because of its high homogeneity in the Yanco area.

Keywords: *Soil moisture, Temporal persistence, Downscaling.*

Standing Water Detection Using Radar

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Abstract: Mapping of natural and man-made water bodies is a critical component of environmental studies, including climate change, agriculture, flood forecasting and groundwater recharge estimation. Moreover, standing water heavily impacts the ability to accurately estimate soil moisture from satellite, particularly from low resolution passive microwave data using a radiometer. NASA's soil moisture dedicated mission, the Soil Moisture Active Passive (SMAP), will use 3km resolution L-band radar to downscale 36km resolution L-band radiometer observations to 9km. These brightness temperature estimates are subsequently interpreted for soil moisture content. Consequently, the 3km resolution radar that will be on-board the SMAP affords the opportunity to also detect dynamic standing water, and thus correct the radiometer signals accordingly prior to downscaling.

The objective of this study was to develop and validate a standing water detection method, using radar observations collected from the Soil Moisture Active Passive Experiments (SMAPEx) undertaken near the township of Yanco in the Murrumbidgee Catchment in southeast New South Wales, Australia. There were three water detection methods put forward in this study, including: i) difference in backscatter at different polarizations; ii) direct backscatter threshold; and iii) the ratios between backscatter at different polarizations. These three methods were all applied to the data collected over a known flooding area, so as to compare the feasibility of each method and thus determine the criteria of water body detection.

The direct backscatter threshold method had the best performance for detecting water bodies, which was subsequently applied to radar data over the entire SMAPEx site. In order to validate the capability of this detection method, the derived water map across the SMAPEx site was compared against a range of reference maps, including 1km resolution brightness temperature data, Land Remote Sensing Satellite (Landsat) derived farm dam maps, and aerial photographs taken during the regional flights of the study site area.

To analyze the influence from incidence angle normalization on the backscatter, both normalized and non-normalized data were tested in this study. It was found that the water map derived from non-normalized backscatter was more accurate, due to the residual normalization error when using the backscatter data at its highest spatial resolution (10m). Consequently, the standing water map had the best estimation of water locations when used at coarser resolution (100m) due to the reduction in speckle as compared to data at high resolution (10m). Moreover, some areas were mis-identified as water, especially in grasslands, meaning that the method needs to be used with caution, and that radar is going to be a challenging approach to identify standing water in vegetated fields.

Keywords: *Soil moisture, water bodies, SMAPEx, radar observations*

Retrieval of soil surface roughness from active and passive microwave observations

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Abstract: Spatial and temporal variation in soil moisture plays a significant role in establishing efficient irrigation scheduling, climate change prediction, and sustainable land and water management. Passive microwave remote sensing at L-band is widely recognised as the preferred technique to measure surface soil moisture globally, with spatial resolution ranging from 40-100km. However, passive microwave soil moisture retrieval is highly dependent on ancillary data such as surface roughness, which is difficult to characterise by ground measurement. The National Aeronautics and Space Administration (NASA) is developing the Soil Moisture Active Passive (SMAP) mission, scheduled for launch at the end of October 2014. SMAP will deploy both L-band active (radar) and passive (radiometer) microwave instruments to enhance the soil moisture retrieval capabilities. Consequently, deriving roughness information from the active microwave sensor onboard SMAP provides an opportunity to solve the aforementioned problem. However, it is unclear if roughness parameters derived from active microwave data can be used directly in passive microwave retrievals.

This paper presents a series of roughness-related analysis using data from the Soil Moisture Active Passive Experiment (SMAPEx), conducted in south-eastern Australia in 2010-2011. The SMAPEx airborne instrumentation comprised an L-band radar (PLIS) and radiometer (PLMR), replicating the active/passive configuration of the SMAP satellite. Intensive ground soil moisture sampling was undertaken concurrently with each flight, and surface roughness was sampled within each major land cover type. In this study, three $1km^2$ pixels with relatively homogeneous bare surface were selected, representing three types of roughness patterns: sinusoidal, flat bench and non-periodic structure. Both soil moisture and roughness parameters of these three pixels were retrieved from PLIS backscatter coefficient and PLMR brightness temperature respectively, and then compared with each other.

Results show that soil moisture values retrieved from passive measurements have a much higher accuracy ($RMSE=0.05m^3/m^3$) than those retrieved from active measurements ($RMSE=0.11m^3/m^3$). Active microwave significantly underestimated the soil moisture ($Bias=0.76m^3/m^3$), especially in the top soil moisture range ($0.15\text{-}0.35m^3/m^3$). In addition, the studied pixel with non-periodic structure showed the best roughness retrieval accuracy (RMSE=0.35cm) from active measurements compared with ground measurments, while the algorithm tends to overestimate the roughness at the two pixels with periodic structure (RMSE=0.52cm and 0.63cm respectively). Importantly, it was found that the roughness parameter H_R retrieved from passive microwave was higher than H_R retrieved from active microwave for all pixel types (calculated using two different formulations from retrieved surface root-mean-square height, Bias=0.21 and 0.36 respectively), leading to the conclusion that passive microwave may be more sensitive to larger-scale of roughness than active microwave. However, these results still need to be confirmed with more data points.

Keywords: *soil moisture; surface roughness; Soil Moisture Active Passive Experiment (SMAPEx); active microwave; passive microwave; RMS height*

Use of remotely sensed and forecast soil moisture data for improving monthly streamflow forecasts

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Abstract: Monthly forecasts of streamflow can be extremely valuable for managing and allocating water resources, particularly in a highly variable climate where the historical data alone have limited value in supporting decision making. While it is widely acknowledged that antecedent soil moisture conditions strongly influence catchment runoff from rainfall events, and hence streamflow over the coming month, antecedent rainfall and streamflows are typically used as proxies for initial catchment conditions in statistical streamflow forecasting models. However, these predictors often provide a rather crude approximation of initial catchment wetness for a number of reasons. On the other hand, in-situ soil moisture measurement is expensive and labour intensive; thus, such soil moisture observations are generally unavailable for describing antecedent soil moisture conditions in streamflow models. This study explores the use of two recently available, alternative sources of soil moisture data as direct inputs to a statistical streamflow forecasting model and the respective abilities of these soil moisture datasets to improve one-month-ahead streamflow forecasts. The first source is a global record of remotely sensed soil moisture that was recently developed as part of the Soil Moisture Climate Change Initiative (CCI) project by merging different satellite soil moisture datasets. The second soil moisture dataset is derived from the Predictive Ocean Atmosphere Model for Australia (POAMA), a dynamic climate forecasting system based on a coupled ocean/atmosphere model and ocean/atmosphere/land observation assimilation systems.

The remotely sensed data provide estimates of initial catchment wetness, while the forecast data provide an estimate of average soil moisture over the forecasting period, which may be important at a monthly timescale. However, the satellite-derived soil moisture data only give estimates of soil moisture in the top few centimetres of the soil and at a fairly coarse spatial resolution, while the forecast soil moisture data are provided at an even coarser spatial resolution and their accuracy is heavily dependent on the underlying forecasting model. The aim of this study is to assess whether the information content of either of these datasets is sufficient to improve statistical streamflow forecasts, particularly at a monthly timescale where temporal variations in the soil moisture are smoothed over the month. The performances of four streamflow forecasting models are compared: a "base" model with no soil moisture inputs; two models which use the two different soil moisture predictors separately ("base+RSSM": base model + remotely sensed soil moisture; and "base+FSM": base model + forecast soil moisture); and a model which includes both soil moisture data sets as inputs ("base+allSM"). An artificial neural network is used as the forecasting model and a Bayesian calibration method is employed such that the uncertainty in the streamflow forecasts can be assessed. As can be seen in Table 1, results indicate that a significant improvement in streamflow forecasts can be gained by including both forecast and remotely sensed soil moisture data as inputs to the forecasting model. The largest improvement seems to come from the addition of the forecast data; however, these data are downscaled, with the remotely sensed soil moisture data used to predict the more local conditions. Therefore, it is considered that the combined use of forecast and remotely sensed soil moisture data provides the greatest benefits.

Table 1. Coefficient of determination, R^2 for streamflow models

Model	Training Data (1980–1999, 2005–2010)	Validation Data (2000–2004)
base	0.76	0.63
base+RSSM	0.82	0.62
base+FSM	0.85	0.76
base+allSM	0.93	0.83

Keywords: *Streamflow forecasts, soil moisture, remote sensing, POAMA, statistical modelling*

An Assessment of DInSAR Potential for Simulating Geological Subsurface Structure

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Knowledge of the subsurface properties driving subsidence is of key importance in conducting geophysical surveys such as self-potential, magneto telluric, and reflection seismic, as this can help defining the areas with downward water flow, collapsed features at depth, or overburden affected regions. However, accurate and affordable subsurface information is difficult to obtain with currently available field technology, because changes occur on the time scale of years which means monitoring must be undertaken over extended time periods. Consequently, data are typically limited to borehole logs, well production data, seismic tests, or point subsidence measurements. As these data are laborious to collect, and spatially / temporally sparse, processing Synthetic Aperture Radar (SAR) remote sensing data can provide accurate surface deformation information, which is spatially and temporally dense, allowing to define areas susceptible to subsidence.

To enhance the understanding of the subsurface structure from surface deformation monitoring, a methodology needs to be developed to relate the subsurface data to the high resolution time-lapse remote sensing data in a consistent and regular manner. An accepted technique for monitoring surface deformations is interferometric SAR remote sensing. Here, this approach is applied within the Surat Basin, Australia, to demonstrate its potential to determine the geological subsurface structure. Over the past two- decades, studies in the field of interferometric SAR analysis have focused mainly on generating elevation maps or maps of the deformation induced by unknown underground processes. This research will address the development of a methodology to predict subsurface structural geometries/distribution from surface deformation data, aiming to identify hidden/blind faults or hydraulic barriers using long-term (time lapse) surface observations, as an innovative and cost-effective tool for understanding the subsurface. It is expected that this approach will be able to extend spatially or temporally sparse in-situ datasets, predict subsurface hazards such as sinkholes, and identify where to acquire more in-situ data, thus mitigating risk in resource management.

There are three main focus areas in this research: the monitoring of surface deformation, the simulation of the subsurface structure, and the retrieval of the required subsurface parameters through the use of remotely sensed surface observations to improve the available structural models. To achieve these goals, as an initial step the areas which are susceptible to surface deformation due to ground water extraction are pinpointed using Multidimensional Small Baseline Subset (MSBAS) technique for interferometric pairs of C-, L- and X-band SAR datasets. These observations identify the potential regions for any geological boundaries such as faults or changes in the formation sequence which may have an impact on observed vertical and horizontal deformation signals. For the next stage, it is proposed that these observations could be applied for geophysical inverse modelling to assess the temporal behaviour and impact of boundaries for the observed deformation. By estimating the best parameter space through inverse modelling, it is hypothesized that the previously available subsurface structural model provided by integration of multiple geophysical datasets like seismic, gravity, radiometric and magnetic, may be improved in conjunction with SAR interferometry.

For the Surat Basin, preliminary DInSAR results (ERS-Envisat C-band; 1992 to 2005) show considerable deformation patterns in 2004-2005. These signals are still present in the 2012-2013 interferograms and are coincident with regional underground activities, confirming the anthropogenic impact on subsidence. While this is a promising development, accurate and long term measurement of deformation using such sparse satellite dataset is still difficult to achieve and a more advanced DInSAR processing algorithm for integrating various space-borne SAR data with different acquisition parameters (i.e. temporal sampling, spatial resolution, wave-band and polarization, etc.) is required. This will improve the temporal and spatial resolution of the interferograms. In this study, first results of the DInSAR processing chain over the Surat Basin, including a discussion on the optimization scheme layout are proposed for future use.

Keywords: *Differential Interferometric SAR (DInSAR), subsurface structural modeling, ground water withdrawal, subsidence*

Evaluation of real-time satellite rainfall products in semi-arid/arid Australia

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Abstract: The quality of runoff/streamflow modelling is critically dependent on the quality of rainfall forcing data and a quantitative understanding of its uncertainty. More accurate rainfall data with clearly defined uncertainty has implications for water resource management and flood prediction. This is important for the Lake Eyre Basin (LEB) in central Australia where the landscape is very flat and hydrophobic soils are common. The LEB is also of interest in terms of climate given that it is predominantly semi-arid/arid with a large north-south rainfall gradient. The north is subject to intense tropical (summer-time) based rainfall events, with weaker predominantly winter rainfall occurring in the south where annual totals are approximately 3-4 times lower on average than in the north. The remoteness of this region means that the in-situ rainfall observation network is sparse compared to more densely populated regions across Australia's eastern seaboard, hence the potential of remotely sensed spatial rainfall data to provide useful information here needs to be examined. Three real-time satellite precipitation products, the TRMM Multi-satellite Precipitation Analysis 3B42RT (TRMM-RT) Version 7, CPC Morphed precipitation (CMORPH) Version 1, and Precipitation Estimation from Remote Sensing Information using Artificial Neural Network (PERSIANN), are assessed against in-situ rain gauge data over a nine-year study period to examine characteristics of their error in LEB. An up-scaled version of the Australian Water Availability Project (AWAP) spatial rainfall product (interpolated from gauge data) was also assessed against the same gauge data used for the satellite products, as a benchmark for comparing the satellite product assessments. All data were mapped to a 0.25° resolution grid and aggregated to daily time step rainfall totals (9am to 9am), with errors calculated as differences in daily rainfall between the products and gauge data for the nine-years. Products were assessed by inter-comparing the distribution of their daily errors via boxplots, and through bias (average error) and root mean square differences (RMSD) over the nine-years. The ability of satellite products to detect rain gauge measured events was also examined via calculation of the Probability of Detection (POD) and False Alarm Ratio (FAR) metrics.

Based on error distributions for each rainfall product over the full nine-years, TRMM-RT is the closest match to gauge observations of the three satellite products. Its mean bias is ~0.3 mm/day, approximately 3.5 and 4.5 times less than that of CMORPH and PERSIANN respectively, while the unbiased Root Mean Square Difference (RMSD) of ~4.3 mm/day for TRMM-RT is less than half that for both CMORPH and PERSIANN. Comparisons of product error distributions show consistently lower variation and less extreme outlier values occurring for TRMM-RT error. In addition, while the median TRMM-RT error displays a trend of increasing negative bias with increasing rainfall totals, the median CMORPH and PERSIANN errors show the opposite and steeper trend. Common amongst all of the products is an increase in absolute error ranges with increasing daily rainfall totals, in addition to absolute errors calculated over wet season months (mostly summer) having a generally larger spread than over dry season months (mostly winter) in the basin's tropical north. The results provide insights into how error for a product such as TRMM-RT may be best modelled. There are a number of extreme errors in all products, shown as outliers in boxplots, and mostly implying large over-estimates of rainfall. By defining extreme outlier error values as >20 mm/day and/or >100% of gauge values, a sample of these were found to occur at or near the edge of major rainfall systems as delineated by the TRMM-RT products, indicating they may be an artifact of spatial inaccuracy in resolving the edges of rainfall extents, warranting further study. POD and FAR metrics for TRMM-RT further demonstrated differences in performance across ranges of daily rainfall totals, and between tropical wet and dry seasons in the LEB. POD results show there is generally greater chance of detecting the presence of larger rainfall accumulations. From FAR statistics, false alarms are generally more prevalent amongst smaller TRMM-RT estimates and in dry seasons, where FAR values decrease in relation to increasing average TRMM-RT estimates.

Keywords: *Rainfall, remote sensing, rain gauges, error estimation.*

Calibration of Land Surface Model Using Remotely Sensed Evapotranspiration and Soil Moisture Predictions

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Abstract: Calibration is the process of estimating the optimal parameters for a model to accurately reflect the real system, using historical records of system data. The model calibration, however, is frequently limited by availability, quality, quantity and the nature of the ground observations. Lack of streamflow observations in the vast majority of the world, for example, constrains the calibration of hydrologic and land surface models. In this study, an attempt is made to calibrate a land surface model by using satellite retrievals of soil moisture and evapotranspiration (ET), without relying on streamflow measurements. This paper examines the capability of using satellite measurements for the calibration of hydrologic/land surface models for ungauged locations.

The Australian Water Resources Assessment Landscape model (AWRA-L) modified to have single hydrological response unit (HRU) per each grid cell is chosen, as a simple land surface model that requires minimum forcing variables. Initial parameters for the control case are generated based on the fraction of trees and the Budyko's dryness index. Microwave soil moisture retrievals from the Advanced Microwave Scanning Radiometer-EOS (AMSR-E) and daily estimates of ET from the Moderate Resolution Imaging Spectroradiometer (MODIS) are adopted to calibrate a selection of the AWRA-L parameters. Shuffled complex evolution uncertainty algorithm (SCE-UA) is employed to perform local calibration at 25-km grid cell in the Kyeamba catchment, southeastern Australia.

Multiple criteria objective function for calibration is selected based on the AWRA-L output behavior of evapotranspiration and soil moisture compared to respective remote measurements. It considers the bias and the correlation between observed and simulated evapotranspiration and the correlation between observed and simulated soil moisture. Calibration experiments are carried out in daily time step from 2003 to 2007 and validated from 2008 to 2010. The optimum parameters obtained are employed to calculate the monthly average runoff ratio and is evaluated against the runoff ratio derived from streamflow observations at Kyeamba catchment.

The results show that the calibration of AWRA-L using remotely sensed evapotranspiration and soil moisture can improve the predictions of evapotranspiration and runoff. Validation conducted in a separate period also exhibit improvements in the prediction of evapotranspiration, whereas the improvement in soil moisture is trivial during both calibration and validation periods. The monthly runoff ratio estimated after calibration is improved compared to the runoff ratio in the control case. This indicates the potential of calibration with evapotranspiration and soil moisture in improving streamflow predictions. Further research is warranted to increase efficiency in prediction of runoff ratio, so that the calibration scheme can be applied in the regions with sparse or no gauging stations.

Keywords: *Australian Water Resources Assessment Landscape model (AWRA-L), evapotranspiration (ET), soil moisture, calibration, validation, runoff ratio*

Error characterization of microwave satellite soil moisture data sets using Fourier analysis

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Abstract: Soil moisture is a key geophysical variable in hydrological and meteorological processes. Accurate and current observations of soil moisture over meso to global scales used as inputs to hydrological, weather and climate modelling will benefit the predictability and understanding of these processes. At present, satellite platforms are active in mapping global surface soil moisture jointly at sub-daily intervals and mesoscale resolutions. However to correctly interpret observed variations and assimilate them in hydrological and weather models, the error structures of the retrieved soil moisture data need to be better understood and characterised.

In this paper we investigate the utility of a recently proposed method to quantify the variance of stochastic noise in passive and active satellite soil moisture products. While it is typical to analyse the difference between satellite retrievals and ground truth in the *time* domain, this method is based on quantifying the differences between retrieved soil moisture and a standard water-balance equation in the conjugate *Fourier* domain. The method, which referred to as Spectral Fitting (SF), is applied to estimate the errors in passive and active retrievals over Australia (10-44^{o} South, 112-154^{o} East). In particular we consider the AMSR-E (Advanced Microwave Scanning Radiometer – Earth Observing System) LPRM (Land Parameter Retrieval Method), CATDS (Centre Aval de Traitement des Données SMOS) SMOS (Soil Salinity and Ocean Salinity), and TU-WIEN (Vienna University of Technology) ASCAT (Advanced Scatterometer) soil moisture products. The results are compared against the errors estimated using the standard method of triple collocation (TC) with AMSR-E, SMOS and ASCAT as the data triplet.

Our analyses show that the SF method is able to recover similar and reasonable error maps that reflect sensitivity of retrieval errors to land surface and climate characteristics over Australia. As expected, more vegetated and wetter areas are usually associated with higher errors. Additionally for SMOS and ASCAT, the dry cooler desert areas of southern Australia also show higher errors, in contrast to lower errors over the hotter dry desert of central Australia. The reverse is the case for AMSR-E. These patterns are also reflected in the spatial error maps of TC analysis and the direct comparisons of SF and TC estimates show moderate-to-good correlations: 0.64 for AMSR-E, 0.68 for SMOS, and 0.68 for ASCAT. However the SF yields lower estimates than TC at the high end of the range. On one hand, this is perhaps expected given rationale of the SF method to estimate only the stochastic/high-frequency components of the total errors. On the other hand, the simple error model and implementation of TC with non-coincident overpass times can also over-estimate the errors.

This work therefore presents an additional perspective on satellite soil moisture observation errors (in the Fourier domain) that may complement other error estimation approaches (in the time domain), thereby improving our understanding of the sources and types of errors.

Keywords: *Soil moisture, Satellite remote sensing, error characterization, Fourier analysis, triple collocation*

Downscaling of coarse-resolution radiometer brightness temperature by high-resolution radar backscatter

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Abstract: Given the importance of soil moisture for hydrological applications, such as weather and flood forecasting, passive microwave remote sensing is a promising approach for retrieving soil moisture due to its high sensitivity to near-surface soil moisture, applicability to all weather conditions, direct relationship with the soil dielectric constant, and reduced effects from vegetation and roughness. However, passive microwave (radiometer) observations suffer from being relatively low spatial resolution, on the order of 36 km. It is proposed that this scale issue may be overcome by using active microwave (radar) observations, which have much higher resolution when using Synthetic Aperture Radar (SAR) techniques (<3km), and this is the approach being taken by NASA's Soil Moisture Active Passive (SMAP) mission, with a scheduled launch in late 2014. The rationale behind SMAP is to use the synergy between active and passive observations in a downscaling approach to overcome the individual limitations of each observation type, and ultimately provide a merged soil moisture data set at intermediate resolution (~9 km).

The objective of this study is to test the proposed baseline downscaling approach for the SMAP mission using airborne data, thus assessing its viability for future application to SMAP data. The approach is based on the hypothesis of a near-linear relationship between radiometer brightness temperature (*Tb*) and SAR backscatter (σ), and has thus far received very limited testing. The experimental dataset used in this study was collected during the Soil Moisture Active Passive Experiment (SMAPEx) field campaigns over a study site in south-eastern Australia approximately 38km × 36km in size, equivalent to a SMAP radiometer pixel. This research focuses on the brightness temperature downscaling algorithm; according to the SMAP Algorithm Theoretical Basis Documents these downscaled brightness temperatures will subsequently be converted to soil moisture at fine resolution through the traditional passive microwave retrieval algorithm.

The baseline downscaling algorithm was applied to high resolution data from SMAPEx, which include 1km resolution brightness temperature collected by the Polarimetric L-band Multibeam Radiometer (PLMR) and ~ 10m resolution backscatters collected by the Polarimetric L-band Imaging Synthetic aperture radar (PLIS). To minimize noise in the radar data and to approximate the SMAP radiometer/radar pixel ratios (36km *Tb* to 9km resolution using 3km σ) the PLIS data were aggregated to 250m resolution, so as to downscale 1km *Tb* to 250m resolution, thus keeping the same ratio of radiometer/SAR spatial resolution as the SMAP mission. Results showed that the Root-Mean-Square Error (RMSE) in *Tb* downscaled at 100m resolution was around 10*K* at *h*-polarization and 8*K* at *v*-polarization over a cropping area. This RMSE was reduced to 9*K* and 7*K* respectively when downscaling to 250m resolution, due to a decreased spatial heterogeneity during averaging. It was also noted that results at *v*-polarization were slightly better than those at *h*-polarization, since the backscatter is more linearly related to *Tb* at *v*-polarization than *Tb* at *h*-polarization. The accuracy of the downscaling over grassland sites was improved by approximately 3*K* with respect to the cropping area. This was attributed to the more heterogeneous conditions in cropping areas, compared to the relatively uniform conditions in the grassland area. However, one limitation of this study was the availability of only three days of data for estimating the linearity between radar and radiometer observations.

Keywords: *Downscaling, Brightness temperature, Radar backscatter, SMAP, SMAPEx*

Identifying safe drinking water source for establishing sustainable urban water supply scheme in Rangunia municipality, Bangladesh

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Abstract: Safe drinking water source identification is one of the vital components for designing and establishing an urban water supply system. Nowadays, water consumption in a country is one of the determining factors related to its development activities. Rapid growth of population and increased urbanization activities particularly in developing countries offer great challenges to the water utility managers and service providers. In this context, a major challenge is to ensure adequate supply of water with acceptable quality to every city dwellers with minimum cost. However, it is quite difficult to achieve this target, if there is a shortage in water availability from the existing sources imposed by water quantity and quality issues. Therefore, a comprehensive assessment task should be undertaken prior to designing and establishing a long-term water supply options in an urban area of a developing country like Bangladesh.

In Bangladesh, municipal water supply scheme mainly depends on the conventional water sources such as surface water from the rivers and groundwater from the underlying aquifer. Although the groundwater quality is satisfactory for drinking purpose and available abundantly in the shallow aquifer, quality limitations of surface water impose economic constraints with additional treatment cost for system operation. Nevertheless, water availability in both sources may vary from place to place, and must be quantified before any planning and development of water supply scheme. Hence, this study attempts to identify appropriate conventional water sources by mathematical modelling as an assessment case study before establishing a sustainable urban water supply scheme at Rangunia municipality in Bangladesh, where there is no water supply system at present.

Water demand in the Rangunia municipality is estimated up to the design year of 2040 based on the available population census data. Based on the regional model assessment results, suitability of surface water and groundwater sources against the existing and projected water demand has been evaluated. The Eastern Hill Region Model (EHRM) developed and maintained by the Institute of Water Modelling (IWM), Bangladesh is used for surface water source assessment. The flow simulation in the EHRM has been carried out by using MIKE-11 software. For developing groundwater model, the hydrogeological setting and aquifer demarcation in the municipality area is accomplished by analyzing the individual hydrostratigraphic sections produced from the borehole lithology. The groundwater model domain covers a larger area (4574 sq. km.) to avoid the boundary influence in model computation, which includes the study municipality (13.34 sq. km.). Therefore, the developed groundwater model of the study area spreads over 22 upazillas (sub-districts) of Chittagong, Rangamati and Khagrachhari districts in the eastern part of Bangladesh. Groundwater simulation is carried out in an integrated MIKE-11 and MIKE-SHE software platform.

The simulation results along with measured water quality parameters indicate that none of the surface water and groundwater source is suitable for long-term water supply option in Rangunia municipality even though adequate quantity of water is available from both sources. Surface water source is highly associated with water quality issues based on Bangladesh drinking water standard, whereas groundwater level shows a decline trend on long-term exploitation. Therefore, the present study concludes that upon having a suitable treatment of surface water, existing surface water and/or groundwater sources can be used as safe drinking water sources for developing sustainable water supply scheme in Rangunia municipality of Bangladesh.

Keywords: *Mathematical modelling, Rangunia municipality, EHRM, Urban water supply, Conventional water source*

Multivariate statistical approach for modelling domestic water demand of Dhaka city in Bangladesh

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Abstract: Water demand modelling and prediction are essential components for planning and management of water resources components. It is also important for cost-effective design and long-term operation of various urban water supply infrastructures. Rapid urbanization and uncontrolled population growth triggers higher water stress, which is a reality in many water deficit regions of the world. This leads to the paying of immediate attention for management of water resources in an effective manner in highly urbanized areas. Water demand management comes to be an appropriate strategy aiming to effective and sustainable urban water consumption in terms of economy and environment. Therefore, appropriate and user-friendly techniques are highly necessary to predict the future water requirement accurately. Domestic water demand is the most important component of municipal water consumption. Water demand usually is a complex function of different socio-economic variables and meteorological parameters, which is forecasted either by analyzing historical water consumption or based on statistical models with a range of these variables.

Dhaka, the mega city of Bangladesh covering an area of 360 sq. km. contains more than 16.4 million people that obviously creates huge burden on urban water supply systems. Due to uncontrolled exponential growth of population and rapid urbanization, the Dhaka Water Supply and Sewerage Authority (DWASA) is currently facing tremendous challenges to maintain reliable water supplies to the city dwellers. City water supply mainly depends on the groundwater and surface water sources. About 87% of the total supply comes from the underlying Dupi Tila aquifer through the operation of numerous deep tube wells and the remaining portion comes from the surface water source mainly from the surrounding rivers around the city. Every year groundwater table is declining by 2-3m for more withdrawal. The river water is also highly polluted, which in turn introduces higher treatment cost. That is why supply management is no more a viable solution for the city and a demand side management approach is essential. In order achieve this, the first and foremost step is to undertake a research about water demand analysis and forecasting. Therefore, the present study is a very initial attempt to develop and compare different water demand models for Dhaka city based on the multivariate statistical approach.

Different socio-economic and climatic data are collected from the relevant organizations in Bangladesh. For accurate understanding of the existing water consumption patterns and the variables controlling the water consumption of the city dwellers, the statistical analyses are performed. Also, the most explanatory variables that influence the statistical demand function are identified. The model applies statistical tools for selecting the appropriate demand function and most relevant explanatory variables. The analysis indicates that the number of connections, water pricing, average annual temperature, annual rainfall, and number of deep tube wells are significant variables of domestic water demand characteristics in the city.

Three different statistical models namely linear model, semi-log model, and log-log model have been established by using three different demand functions. Model accuracy has been checked based on different goodness-of-fit measure parameters in all cases. Residual plot for all models are drawn to investigate the acceptance of the developed models. Based on the statistical approach (highest adjusted R^2 and least standard error), error parameters and residual plots, a comparison has been made to select the best model. The analysis demonstrates that log-log model replicates the city's water consumption patterns satisfactorily with least errors and highest adjusted R^2. However, the study identifies that number of connections, and number of working deep tube wells are the most explanatory variables related to water consumption patterns in the city. Based on the statistical analysis and results obtained, the study concludes that the log-log model is most suited for defining water demand patterns in the city. This study suggests that these models can be updated in future by incorporating more relevant variables for successful application in predicting and managing the domestic water demand in Dhaka city of Bangladesh.

Keywords: *Demand function, Domestic water demand, DWASA, Multivariate statistical approach, Water consumption patterns*

Assessment of the first flush phenomenon in three catchments with different land uses

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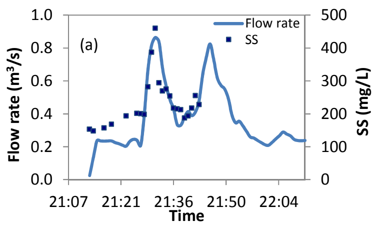
Abstract: The first flush is the discharge of a larger mass or higher degree of concentration of pollutants in the early part of a storm. This phenomenon is assumed for a single event for a given water quality parameter. Quantification of the first flush effect in stormwater runoff is important for accurate design of best management practices. Various methods have been proposed to define the first flush. Some of the definitions include existence of a first flush effect if 80% of the pollutant mass is discharged in the first 30% of the runoff. Other definitions include the first 20 to 40% of the runoff volume where mass emission rates are relatively high. This traditional approach is adopted in most first flush management strategies. Many models and experiments have been proposed to understand the first flush effect based on the traditional approaches. The unique nature of each rainfall event complicates both the stormwater hydrograph and pollutograph characteristics by addition of local environmental features such as dry weather periods, different pollutants types, topography etc. This study aims to carry out an assessment of the first flush in urban runoff in three catchments of different land-use. It also discusses the limitations associated with existing methods to quantify the first flush effect.

Stormwater samples were collected from 3 catchments, located in Sydney (1.1 ha) and Brisbane (34 ha) in Australia and Winterthur (8.4 ha) in Switzerland. The first 5 mm of runoff was collected from the Sydney catchment (commercial, n=6), the first 8 mm of runoff was collected from the Brisbane catchment (residential, n=4), and the first 3 mm of runoff was collected from Winterthur (road, n=9) using auto-samplers each having 24 sets of bottles, where n= number of samples. The first 40% of the rainfall volume (first flush), as commonly defined in the literature, was ~4 mm, ~6 mm and ~2 mm for Sydney, Brisbane and Winterthur, respectively. The auto-samplers were programmed in such a way that they could capture the first flush runoff volume in all three sites. The collected samples were filtered through 1.2 µm filters and were then weighed to measure the suspended solids (SS) concentration. Figure 1(a) shows the dynamic behavior of flow rate and the variation in suspended solids concentration in one of the events and Figure 1(b) shows initial and maximum suspended solids concentrations in stormwater in the six events in the Sydney catchment. Figure 1(a) shows that both flow rate and suspended solids concentration are following similar trends. However, due to instrumentation limitations, suspended solids could not be collected after 5 mm runoff (later stage of the hydrograph where flow was still rising (after 21:45)). This means our first flush sample collection method could not capture the full first flush in the true sense. It is estimated that the cost of stormwater treatment would be ~AUD 2/kL in Australia. This first flush volume that requires treatment are 277 kL, 168 kL and 18849 kL and would cost around \$550, \$336 and \$37,700 for Sydney, Winterthur and Brisbane, respectively. Changing of first flush volume with events demonstrates that traditional fixed volume approach may not define the first flush effectively. Redefinition of the first flush based on real time monitoring is urgently required to minimize treatment costs and ecological risks.



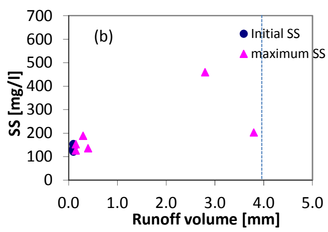


Figure 1: a) Suspended solids concentration with flow rate in a single runoff event and (b) initial and maximum concentrations in six events.

***Keywords**: stormwater, first flush, treatment cost*

Modeling water use in schools: a comparative study of quarterly and monthly models

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Abstract: Urban water supply systems provide water for a range of water uses from human consumption to fire control, and from garden irrigation to industrial processes. The amount of water consumed in an urban area depends on the activities. Therefore, urban water use is categorised into different sectors such as residential, non-residential and unmetered water use.

Modeling urban water use has significant importance in water resources planning and management. From the literature, a vast amount of research was found on modeling residential water use. However, a significant portion (e.g. around 30% of total water use in Melbourne, Australia) of urban water use belongs to non-residential, and limited attention has been given to modelling non-residential urban water use, possibly due to the difficulty of data collection at end-use level. However, billing data are now available in monthly and quarterly time steps with the latter being widely available. Such data can be utilized to build models for predicting non-residential water use.

Therefore, this study aims to develop non-residential water demand models by identifying unique groups based on their homogeneous nature of water use and then further disaggregated into different sub-groups based on their volumes of water uses. Quarterly billing data from 2000 to 2011 were obtained within the Yarra Valley Water (YVW) service area for 46,000 non-residential customers. Of them, monthly water use data available only for 100 customers. Therefore, comparative study of quarterly and monthly time step modeling was carried out by developing a regression model to predict non-residential urban water use in two schools within YVW service area and is presented in this paper.

Monthly water use data from 2005 to 2011 were used for this study as water usage patterns are significantly different in pre and post 2005 due in part to permanent water saving rules, which was introduced in 2005. Monthly data were accumulated into quarterly data for developing the quarterly model. Past water use, dummy variables for fixed quarterly effects, incidence of water restrictions, total rainfall and mean monthly maximum daily temperature were considered as influential variables. Although there were five levels of restrictions during this period, due to insufficient data points for some of the restriction levels, all types of restrictions were considered as a single level of restriction. Model performance was measured using Nash-Sutcliffe efficiency (E) and relative error values.

Model calibration and validation were performed using two independent data sets by splitting the total record into two periods. Two sets of calibration periods: 2006-2009 and 2006-2010 and validation periods: 2010-2011 and 2011 were also tested to find the best period for model development and validating the models. It was found that the models developed with 2006-2010 calibration period have given better results for both of the schools.

Although, both of the monthly and the quarterly time step models were found to predict well, quarterly model performed slightly better than the monthly model with less relative error and good E value.

Keywords: *Non-residential urban water demand, Modeling, Regression, Monthly, Quarterly, School.*

A stochastic model of domestic water consumption and greywater generation in the Al Ain city

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Abstract: The sources of urban water in the United Arab Emirates are groundwater, desalinated water and treated wastewater. About three-quarters of desalinated water are used for irrigation to amenity plantations. Water consumption in major cities varies between 170 and 200 liter per capita per day (Lpcd) in flats and between 270 and 1760 Lpcd in villas. Irrigation to roadside plants, home gardens and to recreation areas has been increasing in the region with the rapid growth of its urban development. Diversification of water sources and water demand reduction are therefore considered two vital tools for the security of urban water supplies. Currently about 98% of municipal wastewater are centrally collected through an efficient sewerage networks and then treated for reuse to provide irrigation to roadside plantations. The treated wastewater is not conveyed to houses because of the necessity of dual reticulation systems. Reuse of greywater (household wastewater except from kitchen and toilet) for non-potable consumptions (gardening and toilet flush) can be an alternative. The objective of this study is to investigate the potential for decentralized (individual houses) harvesting and reuse of greywater in Al Ain city for non-potable consumptions. An attempt has been undertaken to estimate domestic water consumptions and greywater generation in the city. The frequency and water volume of personal water uses (shower, ablution, toothbrush, hand wash, face wash, toilet flush) and family water uses (laundry, dish wash, home clean, car wash, pet wash, gardening) were estimated from 100 homes randomly distributed across the city. Their probability distributions were fitted using the normal, log-normal, gamma and logistic distributions. The estimated average greywater generation rate was found to be 195 Lpcd. For personal water uses, highest consumption was observed in shower, toilet flush and ablution accordingly. About 70% respondents considered greywater can be reused for gardening. Considering the high variability of water uses frequency and time requirements, the probabilistic model is recommended for greywater quantitative analysis.

Keywords: *Water consumption, greywater generation, water uses frequency, probability distribution.*

Development of a framework for the valuation of Eco-System Services of Green Infrastructure

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Abstract: With the rapid urban growth and development, the quality of green space available is consequently been degrading. Furthermore, many land characteristics have been altered such that the whole water cycle has been significantly changed. Some of the considerable adverse effects occur by these changes include the increase of runoff which can lead to flooding and the poor quality of receiving waters. Therefore, to improve the quality of the prevailing surface conditions whilst managing the stormwater, Green Infrastructure (GI) have been introduced which is becoming one of the promising practices of restoring the natural environment across many countries around the world. The term GI in the literature is commonly referred as Low Impact Development (LID), Best Management Practices (BMP), Sustainable Urban Drainage Systems (SUSD), Water Sensitive Urban Design (WSUD) and Low Impact Urban Design and Development (LIUDD) in different contexts (Eliot and Trowsdale, 2006). GI in broader terms can be defined as an "interconnected network of green space that conserves natural systems and provides assorted benefits to human populations" (McMahon and Benedict, 2006). GI can be grouped into two main categories structural and non-structural. The former include green roofs, rainwater tanks, wetlands, bio swales, pervious pavement, stormwater detention systems, planter boxes, cisterns, rain barrels and downspout disconnection amongst others. Nonstructural GI is designing the buildings or roads to minimize the imperviousness, improvement of the infiltration ability of soils by amending the properties and improving the vegetation of specific site or region. (Eliot and Trowsdale, 2006)

Though GI is best known as an alternative to conventional stormwater management strategies, it has been proven that apart from managing stormwater GI can provide a wide range of benefits known as Eco-system Services (ESS) (CNT, 2009). Such benefits include reducing Urban Heat Island (UHI), improving air quality, saving the energy, climate change and adaptation, improving habitats and community livability amongst others. Currently, different countries across the world are committing investments on promoting the benefits of having GI within their communities and therefore it is very important to have a comprehensive study on the value of the ESS they can provide. Such holistic assessment will demonstrate to stakeholders as well as the general public that the application of GIs not only a stormwater management strategy but have many social and environmental benefits. Furthermore, when these benefits can be transferred into monetary value then wider community will appreciate the importance of GI implementation in their society.ESS of GI in six main initial categories. They are water, energy, air, UHI, climate change and community liveability.

The ESS of GI can be studied in terms of environmental, economic and social benefits. Since the representation of benefit of each of the ESS in monetary terms can concentrate the results in to a final common resource unit, the economic benefits of these practices can produce are used for the cumulative valuation in the framework development. The valuation is done by using formulas adopted by different researchers in previous studies and applied for the conditions in Melbourne Australia. Melbourne is the second largest city in Australia with a highest rate of urban growth. Due to this scenario the green space available within the area is alarmingly degraded by creating the importance among professionals and government bodies in developing new ways to improve the region's natural environment. Therefore, the aim of this project is to develop a framework for valuing ESS of GI for Melbourne, Australia. The framework is then applied to a hypothetical case study with a green roof area of 300 square meters considering rainfall, temperature, and pricing for utilities in Melbourne area. The results of the ESS assessment indicates that a green roof located in Melbourne can approximately reduce 93 kiloliters of rainfall runoff per year and provide an economic benefit of 1245 AUD per annum by considering its energy, air quality and climate change benefits.

Keywords: *Green Infrastructure (GI), Eco-system Services (ESS), benefit valuation*

A framework for optimizing residential water reuse at the cluster scale: performance trade-offs when choosing between water sources and scale of implementation

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Abstract: In many regions, climate change, ageing infrastructure, population growth and rising per capita demand are affecting the balance between demand and supply of water. When supplies are unable to meet demands, water utilities generally respond through demand management or developing new water resources. Yet, in many arid and semi-arid regions, all current surface and groundwater sources are fully developed, over allocated or simply unsuitable for water supply. Therefore, alternative water sources are being sought, including the use of greywater and rainwater. These sources are often implemented at the household level. However, economies of scale are present in many infrastructure components of water supply systems. Yet few studies have comprehensively analysed what the performance tradeoffs are at different scales across the entire water supply system. In this presentation, an optimisation framework for assessing the performance of alternative water sources across a number of scales is introduced and applied to a case study.

The framework is based on the systems approach. This approach, proposed by Biswas in 1976, becomes more important in the light of resource scarcity, because optimal decisions are more important when resources are scarce. The systems approach can incorporate optimisation in the comparison of alternative designs across a number of sustainability indicators. In this regard, the framework involves: (1) selecting objectives, (2) identifying available water sources, (3) mapping sources to end-uses forming water subsystems, (4) specifying the scales, that is the number of houses connected to each subsystem, for analysis, (5) forming complete water systems from these subsystems and scales, (6) modelling and designing these systems, using optimisation, to calculate objective function values, and (7) comparison of performance of systems at different scales in a multi-objective manner.

The case study considered a realistic greenfield development, located in an semiarid climate, within a rural township. Blackwater, greywater, rainwater and mains water are considered as potential water sources. Scales considered consist of clusters with a median of 1140, 570, 285, 96, 37 and 17.5 allotments. Economic cost, energy requirements and water savings are assessed for each water system. A number of components contributed to the costs and energy requirements, including collection and distribution piping, trenching and refill, storage tanks, in addition to the building and operation of treatment plants and pumping stations. Multi-objective genetic algorithms are used for selecting storage tank capacities and pipe diameters.

Results show that treatment aspects dominate costs; it is significantly cheaper to treat better quality sources (e.g. rainwater as opposed to a greywater/blackwater mix). However, water savings are dominated by seasonality of supply. For example, while greywater supply is constant throughout the year, rainwater has seasonal dynamics; winter rains are often lost through overflow, but are needed mostly in summer. In addition, strong correlations exist between economic costs and energy requirements – costlier products tend to have larger embodied energy. However, slight tradeoffs exist between energy requirements and costs within distribution networks. Smaller diameter pipes result in lower costs, at the expense of greater energy requirements as pumps have to provide greater pressure.

In regard to scale, diseconomies of scale are present in collection and distribution networks. Piping becomes more costly at larger scales, as larger diameters are needed to convey higher flows. In addition, pumping becomes more expensive at larger scales due to higher frictional losses caused by greater pipe lengths. However, these diseconomies of scale are dominated by the economies of scale in treatment and pump station capital costs, and the running costs of treatment plants.

Keywords: *Water reclamation, rainwater, greywater decision support, multi-objective optimisation, sustainability, economies of scale*

Modeling the effects of Urban Growth Scenarios on Water Demand and Runoff Patterns in Dublin, Ireland

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Abstract: The concept of sustainable urban water management involves managing the urban water cycle in a holistic manner by integrating the water supply, wastewater and stormwater management of a city to achieve better assimilation of the urban and natural water cycles.

In response to the emergence to this new paradigm, decision support models have been developed to facilitate integrated modeling of the urban water cycle and to provide functionality for comparing options for alternative water management options. Outputs typically include indicators such as whole life costs, water flow indicators and energy use. Available models however have shortcomings and tend to have limited capacity to incorporate urban land use changes and the significant but related effects that different urbanization scenarios will have on the urban water cycle.

Against this background, the Dynamic Urban Water Simulation Model (DUWSiM) has been developed. DUWSiM is a computer based model that links a cellular automata land use dynamics model (MOLAND) with concepts from existing water balance models. DUWSiM simulates major components of the urban water cycle including, evaporation, runoff, water demand, water supply and wastewater on a daily time step and incorporates urban land use change scenarios on an annual basis for 20 years into the future.

DUWSiM has been applied to the Greater Dublin Water Supply area in Ireland to assess the effects of four urban development scenarios based on regional planning policies on water demand and stormwater runoff from 2007 - 2026. It was shown that significant differences in water demand and stormwater runoff exist between urban planning scenarios and it was concluded that urban planners and urban water managers need to collaborate in order to develop effective long-term strategies for the urban water sector.

The scenarios assessed were all based on the same population and economic projections and all assumed low and medium density development of urban fabric. Future research should assess the combined effects of regional planning policies, population and economic projections, climate change and urban form (low density vs. high density/compact development) on the urban water cycle.

Keywords: *Runoff, Water Demand, Urbanization, Urban Growth, Urban Water Management*

Using multi-criteria analysis models for the prioritisation of investment in the Great Barrier Reef

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Abstract: Reef Rescue is the Australian Government's contribution to the Great Barrier Reef (GBR) Water Quality Protection Plan. This Plan's objective is to halt and reverse the decline in the quality of water entering the Reef lagoon. The catchments of the GBR comprise almost 38.5 million hectares; about 82 per cent is used for agriculture; in 2010-11 the gross value of agricultural production totaled $4.25 billion. Declines in the ecosystems of the GBR have been linked with increases in the land based run-off of suspended sediments, nutrients and pesticides since European settlement.

There has been substantial progress in understanding the sources of pollutants and the link between agricultural land management practices and Reef health through investment in the Reef Plan Paddock to Reef Integrated Monitoring, Modeling and Reporting Program, the Reef Rescue Water Quality Grants and Partnerships program and new science. To inform future investments, a Working Group of scientists from federal and state departments, the Great Barrier Reef Marine Park Authority and James Cook University was established to advise on priorities for 46 management units across the GBR Natural Resource Management regions, based on potential for improvement in sediment, nutrient and pesticide management on-farm. (The management units comprise sub catchments flowing to the Reef lagoon for most regions, with finer scale catchments used for the larger Burdekin and Fitzroy regions).

We chose the Multi-Criteria Analysis Shell for Spatial Decision Support (MCAS-S) tool developed by ABARES (free from www.daff.gov.au/abares/data/mcass) to draw together the lines of evidence from water quality modelling, research and practice change transparently, and to explore potential solutions with governments, industry, the science community and GBR regions. These stakeholders had previously contributed to a Multiple Criteria Analysis (MCA) advising on allocation of earlier Reef funding.

MCAS-S facilitates spatial MCA by organising factual information, opinion, policy and management goals in a transparent and logical framework, and is particularly useful in participatory processes. MCAS-S enables users to view and classify map layers, adapt and combine layers to provide insight into key relationships. Stakeholders can see the potential impact of decisions, view alternatives using live-update mapping and produce statistical reports for areas of interest quickly. MCAS-S has been used to inform decision making by the Murray Darling Basin Authority and New South Wales' catchment management authorities.

An MCAS-S data pack has been compiled for agricultural industries in the GBR's 46 management units using GBR Source Catchment modeling constituent loads, assessments of the risk of pollutants to the GBR's marine ecosystems, agricultural practice and other agricultural information. The tool was then used to implement the Assets, Threats and Solvability model for priority setting. The outputs compare the contributions of each industry (bananas, cane, dairy, grains, grazing and horticulture) from each GBR management unit to suspended sediments, nutrients and pesticide loads, the likely risks of these to the marine environment, and for industries where data are available, the room for improvement in management practices.

An initial analysis provided information on regional and industry priorities to applicants for the Reef Rescue Water Quality Grants 2013-14 to 2015-16. The MCA spreadsheet developed as part of this project is used by regions to discuss priorities for their management units. The final MCAS-S results will provide the spatially explicit information needed to sharpen the focus of future investments by targeting the pollutants, GBR management units, industries and practices most likely to improve water quality outcomes for the GBR lagoon.

***Keywords**: Multi-Criteria Analysis Shell for Spatial Decision Support (MCAS-S), reef water quality*

Great Barrier Reef Paddock to Reef Monitoring & Modelling Program

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Abstract: Great Barrier Reef (GBR) catchments have been extensively modified over the past 150 years for agricultural production, leading to a decline in water quality entering the GBR lagoon. A joint Queensland and Australian government initiative produced the Reef Water Quality Protection Plan (Reef Plan) in 2003 in response to the decline in water quality, updating the plan in 2009 and most recently in 2013. The Reef Plan outlines a clear set of water quality and management practice targets for sediment, nutrients and pesticides. Improvement in water quality is achieved through government and landholder investment into improved agricultural management practices.

A Paddock to Reef Integrated Monitoring and Modelling, Reporting program (Paddock to Reef) has been established to measure and report progress towards meeting Reef Plan goals and targets, and to assess the benefits of improved land management practices on water quality discharged to the reef lagoon. The program integrates five lines of evidence including: monitoring of practice effectiveness, prevalence of adoption of improved practices and catchment indicators through time, paddock and catchment modelling, and catchment and marine monitoring and remote sensing.

Paddock to Reef is an innovative program where paddock and catchment modelling is an essential component used to report on progress towards meeting reef water quality targets. An important innovation is the linking from paddock through to catchment scale models to assess the impact of changes in management practices on end of system loads

***Keywords**:* *Source Catchment modelling, water quality targets, management practice*

Great Barrier Reef Source Catchment's modelling: Enhanced simulation and water quality targeting through event based assessment

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Abstract: A decline in marine water quality entering the Great Barrier Reef (GBR) lagoon is associated with terrestrial runoff discharged from adjacent GBR catchments. Reef Plan 2013 outlines water quality targets to address this decline, with the eWater CRC Source Catchment modelling framework used to report progress towards meeting these targets. Catchment modelling is an ideal tool to investigate constituent budgets and the potential impact of management strategies and it follows that the better a catchment model performs spatially and temporally the greater the confidence in targeted management actions. However model assessment data can often be sporadically collected, over different time periods, different locations and from disparate groups of projects. An advantage of the Source Catchment's framework is the ability to generate daily outputs for discrete periods and locations, thus facilitating aggregation of the disparate monitoring data for use in model calibration and validation.

A Source Catchment model has been built for the second largest GBR catchment the Burdekin. The model identifies constituent sources, supply and losses; and explores the impact of a change in land management on loads discharged to the reef lagoon. The Burdekin, like many rivers has had the majority of its water quality sampling located at the end of system gauging station and to better utilise this data in model assessment, events were defined and catalogued by identifying the source of runoff to this site. Speculating; that the process may add to the limited information on the spatial and temporal sources of pollutants within the catchment. An important feature of the Burdekin catchment is the large Burdekin Falls Dam (BFD), and the consensus is that the area below the dam is a major sediment source and an appropriate area for the targeting of ameliorative management action.

The classification system identified 35 flow events between 1986 and 2009 at Burdekin End of valley, of these events, 16 were classed as originating from *"Above Dam"*, 8 *"Below Dam"*, and 11 were classed as *"Mixed"* in origin. Of the 16 *"Above Dam"* events, 11 were classified as discrete flow events from the Upper Burdekin catchment. In contrast the classification system did not identify a discrete sub-catchment source for the "Below Dam" events.

"Below Dam" classified events had the highest event mean sediment concentrations (EMC) 0.62 g/l, since they only contributed 6% of the total discharge, these events contributed just 9% of the total sediment load. In contrast, the *"Above Dam"* events contributed the largest proportion of discharge (41%) and sediment load (42%), with a lower EMC (0.40 g/l). *"Mixed"* events contributed 34% of the total discharge and 39% of the load, with a similar EMC (0.45 g/l) to the *"Above Dam"* events. The classification of *"Other"* had the lowest EMC (0.19 g/l) with 19% of the total discharge and contributing just 9% of the total sediment load.

All events irrespective of classification have a proportion of flow and load sourced from above and below the BFD. Nonetheless, it was possible to estimate the above dam and below dam contribution to the total TSS load for the study period. The analysis suggests that 60% of the total load is sourced from "above the dam" and 40 % from "below the dam" for the assessment period (1986 and 2009)

The work suggests that above the dam sources may generate greater loads then previously considered and should therefore be further investigated. Additionally the source catchment's model assessed in this paper was found to under predict *"Above Dam"* classified events and it appears that a lack of generation from the Upper Burdekin catchment is a likely source of error. Importantly we have outlined a method for utilising water quality data, through event cataloguing of spatial source and daily timestep modelling. A similar approach may prove beneficial for other model users.

Keywords: *Source Catchments, Burdekin, reef water quality*

An integrated water quality modelling framework for reporting on Great Barrier Reef catchments

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Abstract: The Paddock to Reef Modelling (P2R) and Monitoring Program reports on progress towards meeting the Reef Water Quality Protection Plan (Reef Plan) targets. The targets set out in the Reef Plan are designed to improve water quality entering the Great Barrier Reef (GBR) through improving land management practices. Catchment modelling is being used as one line of evidence to report on progress towards Reef Plan targets resulting from investment in improved management practices. The eWater Source Integrated Modelling System (Source IMS) was chosen as the preferred modelling platform for undertaking GBR water quality modelling. The main reason for choosing eWater source was its flexible architecture that enables users to write customised plug-ins to meet specific modelling requirements.

After a review of currently available modelling platforms, it was determined that there was no “off the shelf” software that could meet all of the modelling requirements. SedNet alone could not provide the finer resolution time stepping required, and Source IMS cannot inherently represent many variations of a spatially varying practice like cropping, to the level of detail required to allow subtle changes in management system to have a recognisable effect on model outputs.

To address these issues, and answer the questions being posed by policy makers, customised plug-ins for Source IMS were developed. These plug-ins allowed us to integrate the best available data sources and landscape process understanding into the catchment model. Purpose built routines enabling representations of processes such as the effects of temporally and spatially variable ground cover on soil erosion, aggregation of deterministic crop model outputs directly into the catchment model and the incorporation of SedNet gully and stream bank erosion algorithms were developed. Additional reporting tools were also written to enable rapid interrogation of model outputs. For example, reporting of pollutant loads by subcatchment, landuse, process (gully, streambank, hillslope) for any time period from daily to average annual.

The development of the GBR Source Catchments models demonstrates the highly flexible nature of the Source IMS framework. With flexibility also comes a tendency towards ever increasing complexity. As more involved questions are posed, it is tempting to keep adding to the functionality of the model. Although the modelling framework is capable of supporting complex algorithms it is essential that these are also supported by observed data and understanding derived from experimentation.

Keywords: *Source Catchments Integrated Modelling System, Water Quality, Great Barrier Reef*

Assessing the effectiveness of water quality management of the Great Barrier Reef through marine monitoring and modelling

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Abstract: Halting and reversing declining water quality is a key strategy for maintaining the resilience of coral and seagrass communities world-wide and a major priority for the effective management of the Great Barrier Reef (GBR). Marine water quality continues to be negatively affected by the discharge of excess nutrients, sediments and pesticides from adjacent catchments. Under the Australian and Queensland government's Reef Water Quality Protection Plan (Reef Plan), the 'Paddock-to-Reef Integrated Monitoring, Modelling and Reporting Program' provides a framework for adaptive management that aims to link land management activities in the catchments to water quality and ecosystem health of the GBR. The reporting process draws on multiple lines of evidence and integrates indicators at the paddock, catchment and marine scales. Indicators that describe inshore marine water quality, seagrass and coral condition have been developed through the Reef Rescue Marine Monitoring Program (MMP) and trends in condition assessments are used to evaluate progress towards the Reef Plan 2020 goal for the marine environment.

The MMP was established in 2005, with sites from Cape York in the north to the Burnett Mary region in the south of the GBR. Monitoring results show that land based runoff has the greatest impact on the marine environment in the wet season and that repeated large-scale flood events in recent years, coupled with the year-round re-suspension of fine sediment, are driving long-term changes in ecosystem health. Sediment can smother marine organisms and highly turbid waters reduce the light available for corals and seagrass to photosynthesise. Coral cover on inshore reefs has declined by 34% since 2005 and seagrass meadows are in very poor condition overall. The long time-series of data has enabled the generation of cumulative flood plume exposure maps, which have been combined with end-of catchment loads data to estimate the exposure of key ecosystems to sediments, nutrients and pesticides. The information generated is compared with the Water Quality Guidelines for the GBR (2009), with implications for investment in on-ground actions.

The MMP has provided a robust indication of trajectories of change in inshore marine water quality, seagrass and coral condition in response to land based runoff. Inherent challenges include a spatially and temporally heterogeneous ecosystem across a large scale and multiple jurisdictions, and a long time-lag before management responses translate into measureable changes in marine water quality and ecosystem function. The development of marine and catchment models that integrate physical processes, sediment transport and biogeochemistry will provide a picture of current and future conditions at greater spatial and temporal scales than monitoring alone. Three-dimensional nested models will assist in estimating the cumulative exposure of key ecosystems to pollutant thresholds and predict the outcome of management actions. Other applications of a combined monitoring and modeling approach include scenario testing, setting regionally appropriate and ecologically relevant water quality targets, informing management interventions for oil spills or dredge spoil disposal, modelling the movements of commercially important fish larvae between management zones of the Marine Park, predicting outbreaks of crown of thorns starfish and forecasting the recovery of seagrass meadows from repeated disturbances. In summary, knowledge of the fate of pollutants delivered to the GBR is critical in providing a firm evidence base for prioritising management actions that improve the quality of water entering the GBR.

Keywords: *Water quality, marine monitoring, marine modelling*

Paddock scale modelling to assess effectiveness of agricultural management practice in improving water quality in the Great Barrier Reef Catchments

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Abstract: Agriculture in the catchment areas adjacent to the World Heritage listed Great Barrier Reef (GBR) Marine Park generates pollutants that are a concern for the health of the Reef. Under the Paddock to Reef Integrated Monitoring, Modelling and Reporting program (P2R) of the Reef Plan, the impacts of improved agricultural management practices on water quality entering the GBR are modelled to evaluate the effectiveness of Government water quality improvement policies. The Source Catchments modelling framework estimates loads of pollutants entering the GBR lagoon from rivers. However, Source Catchments does not have the capacity to represent the collection of management practices available to farmers that affect water quality in runoff and drainage at a paddock scale. Therefore, paddock scale agricultural systems models were used to demonstrate the effects of management practice adoption and to provide input to the catchment scale models. Paddock scale models were used because they represent a level of process detail compatible with the management practice investments and implementation on-ground.

A fit-for-purpose modelling approach was used, where the paddock model most suited to a given land use and/or water quality pollutant was applied. Three one-dimensional agricultural systems models were employed; HowLeaky in grains, APSIM in sugarcane with HowLeaky post-processing for herbicides and phosphorous and GRASP in grazing lands. These models share similar soil water balance, ground cover and runoff sub-models. However, they vary in the level of detail, particularly in terms of representing crop growth and in the processes considered, such as pesticide degradation and export.

In grains and sugarcane cropping, the pollutant time-series (e.g. load per day per unit area) in the Source Catchments models was replaced with an output time-series from HowLeaky or APSIM for each soil-climate spatial combination. Management practices were grouped into systems classed as A, B, C or D. The proportion of each of these management systems contributing to the modelled loads was adjusted to reflect data on the prevalence of adoption of improved management practices in the GBR catchment.

In grazing lands, GRASP pasture utilisation and ground cover time-series outputs were interrogated to derive relationships between changes in grazing system management and changes in the USLE C-factors. The USLE is used to predict hillslope erosion in the Source Catchments model. Scaling indices derived from GRASP outputs were used to adjust the USLE C-factors applied in Source Catchments where management practices had changed.

The P2R program has demonstrated the effectiveness of linking paddock scale models or emergent models derived from them with catchment scale models. This has enabled detailed management options to be simulated to investigate broad scale water quality impacts of the adoption of improved agricultural practices.

Keywords: *Paddock to Reef, water balance modelling, HowLeaky, APSIM, GRASP*

Assessing the relative risk of land based pollutants to the Great Barrier Reef

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Abstract: The iconic Great Barrier Reef (GBR) in Australia faces increasing pressure from human activities and has considerable ecological, cultural, social and economic values. Substantial evidence exists that links the degradation of GBR ecosystems, including reduction in coral cover, to declining water quality in the GBR. The loads of suspended sediment, nutrients and pesticides ('pollutants') discharged to the GBR from agricultural and urban development has increased greatly in the last 150 years. The pollutants disperse offshore during summer high flow events and pose a range of threats to valuable GBR ecosystems including coral reefs and seagrass meadows.

We have developed and applied a risk assessment method to guide policy makers and catchment managers on the key land-based pollutants of greatest risk to the health of the two main GBR ecosystems, coral reefs and seagrass meadows. The risk assessment method used a combination of qualitative and semi-quantitative information about the influence of individual catchments, in the 6 natural resource management (NRM) regions, on coral reefs and seagrass meadows. The method uses a Multi Criteria Analysis approach with the application of a spatial multi criteria analysis tool, Multi-Criteria Analysis Shell for Spatial Decision Support (MCAS-S) developed by ABARES (refer to http://www.daff.gov.au/abares/data/mcass) in conjunction with ArcGIS for spatial analysis.

The combined assessment of water quality variables was used to identify the areas of highest relative risk to degraded water quality in the GBR, and hence the areas where coral reefs and seagrass are most likely to be under pressure from degraded water quality. The relative risk was estimated from the areas of coral reefs and seagrass meadows exposed to a combination of defined pollutant thresholds (observed or modelled). The results indicate that the risk is greatest for coral reefs in the Fitzroy and Mackay Whitsunday regions, and for seagrass in the Burdekin and Fitzroy regions.

The combined assessment of these results with end of catchment pollutant load information allows us to draw conclusions about the overall risk of pollutants to the GBR. In summary, the greatest risk to coral reefs and seagrass meadows in terms the potential water quality impact and end -of -catchment anthropogenic loads of pollutants to the GBR is in the Wet Tropics region followed by the Fitzroy and Burdekin regions. However, it is important to reiterate that the rankings between NRM regions are relative, and do not represent absolute differences in the risk to GBR ecosystems.

In conjunction with information on pollutant generation from dominant land uses in the GBR catchments, the results are being used to inform future investment priorities for reducing pollutant runoff to the GBR under Reef Plan 3 and Reef Rescue 2. The methods are relevant for application in other management settings where combination of information from a range of sources is required and where weighting of factors may be desirable.

Keywords: *Great Barrier Reef, risk assessment, pollutants, water quality*

Catchment modelling scenarios to inform GBR water quality targets

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Abstract: The Great Barrier Reef (GBR) Water Quality Plan outlines a clear set of water quality and management practice targets (50% reduction in nutrients and photosystem II (PSII) herbicides by 2013, 20% reduction in TSS by 2020). Five lines of evidence have been used to report on progress towards reef plan targets due to investment into improved agricultural management practices. This paper provides an overview of the results from one line of evidence, catchment modelling.

The eWater CRC Source Catchments modelling framework was used to generate sediment, nutrient and herbicide loads entering the GBR lagoon from 35 reef catchments. Six catchment models were built for the GBR (423, 000km^2). Data was collected for each industry under an A (cutting edge), B (best practice) ,C (common) and D (unacceptable) management practice framework for the baseline year (2008/09) and following implementation of improved management practices. Load reductions were calculated with respect to the baseline load. At the request of the funding agency, Queensland Government Premiers Department, additional scenarios were also run to determine if targets could be met by shifting to an "All A" practice adoption.

The modelling results suggest there was a 6.2% reduction in average annual suspended sediment load leaving GBR catchments due to two years of investment with the greatest reduction from grazing areas. In the case of total nitrogen, the average annual load was reduced by 6.7%, with the greatest reduction from the Burdekin and Wet Tropics NRM regions. The average annual PSII herbicide load was reduced by 14.6%, with 70% of the reduction from the Wet Tropics and Mackay-Whitsunday regions. Improved herbicide management practices in the cane industry contributed to the largest reduction. Modelling suggests that TSS targets could be met under a 50/50 A/B management scenario whilst the 50% nitrogen reduction target may not be met under an All A management scenario. The Source Catchment modelling framework is now established across the entire GBR region, and enables regional NRM groups to use the model outputs to make more informed decisions as to where investment should occur to achieve the greatest load reductions for the least cost.

This paper describes how the Source Catchment modelling framework is firstly used to report on progress in meeting Reef Plan 2009 water quality targets; and secondly to run additional scenarios to assess the potential to achieve the given water quality targets.

Keywords: *Land management, Catchment modelling, water quality targets, load reductions*

Testing two simple pesticide runoff models in Northern Australian agriculture

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Abstract: The Paddock to Reef Integrated Monitoring, Modelling and Reporting program (P2R) (Department of Premier and Cabinet, 2009) is investigating ways to improve agricultural management practices and the quality of water entering the Great Barrier Reef. One of the major risks to GBR water quality is pesticide runoff from agricultural industries. Direct measurement of pesticide fate and behavior is both cost and time intensive. Modelling therefore offers a logical way forward in assessment of improved management scenario to reduce pesticide runoff to the GBR. Modelling also confers the advantage that it can extrapolate from a relatively small experimental database, to a wider range of conditions and years.

The 'Simplified Formula for Indirect Loading caused by runoff' (SFIL) from The Organization for Economic Cooperation and Development (OECD) and the one-dimensional simulation model HowLeaky? are both paddock scale models used for the prediction of pesticide runoff. We tested the applicability of these models to predict paddock scale (edge-of-field) pesticide runoff against experimental data. The experimental data was from two North-East Australian sites with three kinds of cotton management, 'conventional', cotton grown in wheat stubble and Polyacrylamide (PAM) added to irrigation water. The simulations were carried out for the eight most frequently detected pesticides.

The SFIL-OECD modelled total pesticide loads in runoff were 1.4 to 2.8 times lower than measured loads for various pesticides. The HowLeaky? modelled total pesticide load was 5-23% higher than the measured load using parameter values from the literature. HowLeaky? was able to model similar trends in pesticide concentration compared to measured data following small adjustments to the most sensitive parameters. A sensitivity analysis indicated that the most significant model parameter for the SFIL model was pesticide soil half-life, while for the HowLeaky? model soil half-life, runoff curve number and application rate or efficiency were most significant.

The HowLeaky? model was then used to compare pesticide runoff estimates for 'old' (pre-genetically modified cotton) and 'new' pesticides. The rationale for this was that pesticide usage patterns changed significantly with the introduction of genetically modified cotton, particularly with replacement of soil residual herbicides by knockdown herbicides and insecticides with BT cotton. Therefore the pesticide runoff profile has changed accordingly. Comparing the old and new pesticide runoff profiles suggests that use of new pesticides will result in less pesticide runoff in the GBR.

This work demonstrates the value of models for predicting the environmental fate of pesticides and thus accessing the amount of pesticide entering streams. Future work will investigate the ecotoxicological implications of a shift in application patterns towards the 'new' pesticides.

Keywords: *Insecticide, herbicide, cotton, simulation modelling, HowLeaky?*

Modelling river constituent budgets in the Burnett Mary region, Queensland, Australia: An example of how it could be used in prioritising management actions

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Abstract: To improve the declining water quality entering the Great Barrier Reef (GBR), the Australian and Queensland governments are funding changes to on-ground management practices through the Reef Plan Program. Reef Plan 2013, outlines specific water quality targets to address the decline in water quality entering the GBR. For example, it has set a target of 20% reduction in fine sediment export by 2018. An integrated water quality monitoring and modelling program has been established to measure and report on progress in meeting the water quality targets. Current prioritisation of on-ground management actions are based on previous modelling outputs, local knowledge and perception of areas and industries that are likely to generate disproportionately high amounts of constituents. The current Catchment modelling approach will enable more effective prioritisation to catchment areas and pollutant generation processes. This paper reports the results of the recent modelling of constituent budgets using the Source Catchments model outputs including identification of sources of supply to the river system, sinks and contributions to export to the GBR from catchments in the Burnett Mary region, and discusses how this information can be used in prioritizing on-ground management actions. This paper also highlights how examination of modelled constituent budgets can be used to (1) identify parts of the model that may be improved and (2) provide insight into the selection of water quality monitoring sites for model calibration and validation.

Of the total modelled suspended sediment (TSS) supplied to the stream network, only 37% (438 kt) is exported, 46% (541 kt/y) is trapped in reservoirs (estimated by an algorithm used commonly elsewhere but modified to simulate daily sediment trapping in the Burdekin Falls Dam), 17% (198 kt/y) is lost as the result of water extraction while floodplain deposition and residual storage accounted for only 1%. The model estimates that streambank erosion, hillslope erosion and gully erosion contribute 56, 28, and 6% of the TSS exported to the GBR lagoon; with each respective erosion process supplying 29, 27, and 3% of particulate nitrogen (PN), and 28, 33, and 3%, of particulate phosphorus (PP).

Particulate Nitrogen and Phosphorus budgets were similar to the TSS percent exported compared to the total amount generated. On the other hand, the model estimates that higher percentages of dissolved nutrients and Photosystem II inhibiting herbicides (PSII) that are supplied to the stream network (i.e., 68% dissolved inorganic nitrogen (DIN), 67% dissolved organic nitrogen (DON), 67% dissolved organic phosphorus (DOP) and 65% dissolved inorganic phosphorus (DIP) and 67% PSII inhibitor herbicides) are exported to the GBR lagoon.

Having the functionality in the model to identify the specific pollutant sources and generation processes that contribute comparatively high constituent export to the GBR lagoon, will help to maximise progress towards water quality targets. For example, model results show that streambank erosion in the Mary catchment is identified to be contributing the highest proportion of TSS of all GBR catchments. Therefore, streambank erosion reduction through riparian revegetation and fencing off to restrict stock access may be considered to be management actions of priority in this catchment. In summary, the GBR Source Catchments modelling framework has now been developed with a range of enhancements not available in previous modelling programs. The development of the dynamic SedNet Source modelling functionality provides regional NRM groups with valuable information for prioritisation of on-ground management investment.

Keywords: *Burnett Mary, constituent budget, Great Barrier Reef, water quality*

An evaluation of hydrological models for predicting mean-annual runoff and flood quantiles for water quality modelling

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Abstract: Predicting spatial variations in runoff is important for water resource assessment and understanding spatial variation in flood quantile is valuable for assessing flooding risk and sediment loads during floods. Sediment fluxes in river networks are disproportionally sensitive to runoff events, river bank erosion and floodplain deposition. Many spatially disaggregated models of erosion and sediment transport require inputs of long term runoff volume and daily flood quantiles for each link in a stream network. This paper presents an evaluation and comparison of two different hydrological models in predicting catchment water yields and flood quantiles throughout a stream network. Using data from tropical Queensland catchments, a simple regionalization model (SedNet) and a daily time step conceptual rainfall-runoff model (SIMHYD) were calibrated using a set of gauge data and evaluated for ungauged condition using another set of gauge data. Results showed that a daily timestep rainfall-runoff model could provide better calibration to observed water yield but a regionalised model was as good as or better than the daily time step model for calibration to flood quantile. For prediction (on ungauged condition), both models produced similar results in predicting mean annual water yield and flood quantiles, with slightly better prediction of daily flow variability by the regionalised model. Based on an analysis of sensitivity of bankfull recurrence interval, we found large uncertainty in predicting bankfull flow using the SIMHYD model. Results imply that a simple regionalized model is as good as a complex daily time step model for long-term sediment budgets in water quality modelling. Using a daily time step, however, could be necessary if event modelling of flood information and sediment is required.

Keywords: *Flood quantile, performance evaluation, erosion, regionalisation, Great Barrier Reef*

Hydrodynamic modelling of floodplain flow residence time in a wet tropical catchment, north eastern Australia

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Abstract: Vegetated systems (e.g. grassed strips, riparian vegetation, wetlands, sumps) are increasingly being incorporated into farming systems in north Queensland, especially in the catchments draining to the Great Barrier Reef (GBR) lagoon, to improve downstream water quality. The residence time of water in trapping mediums is an important measure of likely effectiveness of any vegetated area. While residence time of catchment runoff in the GBR lagoon before it is transported to the open ocean is reported in many studies, quantitative estimates of water residence time in the river-floodplain system for majority of the GBR catchments is generally unknown. This study focused on the Tully-Murray catchment in the wet tropics which is frequently flooded (2 to 3 floods in each year) and carries a large quantity of land sourced contaminants to the GBR lagoon during overbank flow events. A two-dimensional floodplain hydrodynamic model (MIKE 21) was used to simulate spatial and temporal variations of velocities across the floodplain. This information was used to estimate mean residence time on the floodplain before flood water from agricultural lands reaches coastal waters. The model was calibrated using measured inundation depths and velocities at 53 locations on the floodplain for a recent flood in 2013, which was about 2.3 times bigger than a mean annual flood. A range of water residence times has been extracted for in-channel and floodplain waters for different floods. This information is useful to estimate denitrification, pesticide degradation and sedimentation by combining residence time with pollutant decay rules to assess the effectiveness of vegetated areas.

Keywords: *Floodplain, residence time, vegetated system, water quality, GBR*

Improved mapping of soil erodibility (K-Factor) in the Burdekin River catchment, Queensland, to aid landscape modelling

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Abstract: Good-quality soil information is critical to the accuracy of models of environmental processes. In catchments that drain into Australia's Great Barrier Reef, process modelling is being used to improve understanding of the links between land-management, soil erosion, and sediment pollution of the marine environment. To underpin this modelling effort, we have been tasked with improving the available soil information for the Burdekin River catchment (the Reef catchment with the most severe land-degradation concerns) with a particular focus on those soil attributes that affect soil erodibility. We have applied geostatistical modelling techniques to the existing soil information to map *K*-factor of the Revised Universal Soil Loss Equation, averaged at a resolution of 1 ha.

The calculation of *K*-factor for any mapping pixel requires soil attributes for particle size fractions, organic carbon, structure and permeability for this pixel. Data for these attributes were sourced from existing analytical and morphological soil profile description sites, and were harmonized over the 0 – 5 cm and 5 – 15 cm soil depth intervals (the first two intervals defined in the GlobalSoilMap.net project). Spatial surfaces of environmental covariates were calculated (16 terrain derivates and four gamma-ray spectroscopy covariates), and used to model and map the soil attribute data via a combination of random forest and geostatistical modelling methodology. The resultant spatial surfaces of soil attributes were mapped in rasters with a 1-ha block-averaged cell size. The modelling methods provide a probability distribution of the attribute uncertainty in each pixel. Values for attributes were then simulated and the *K*-factor formula applied, with this repeated to build a predictive distribution for *K*-factor.

Compared with existing maps of *K*-factor derived from polygonal data for ASRIS, the *K*-factor map produced using our method is continuous and relatively smooth. The benefits of the resulting *K*-factor map are:

- it is spatially continuous, which agrees with our general understanding of soil variability.
- the new maps have an improved spatial resolution of 1 ha.
- the new maps can be produced at any desired percentile. This is beneficial if the *K*-factor is to be used as an input to further modelling, as it will enhance sensitivity analysis of the subsequent model.

Keywords: *Soil map, kriging, uncertainty, erosion, K-factor*

Estimating RUSLE C-Factor Values for Great Barrier Reef Catchments using Satellite Derived Ground Cover Estimates

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Abstract: Ground cover is a primary contributing factor in preventing hillslope erosion. Accurate modelling of this erosion is therefore dependent on accurate estimates of ground cover. Ground cover is temporally and spatially variable and, as such, remote sensing is an ideal source of ground cover estimates over large geographic areas. For the Great Barrier Reef, this information has generally been derived from the Remote Sensing Centre (RSC) (within the Queensland Department of Science, Information Technology, Innovation and the Arts) Bare Ground Index/Ground Cover Index (BGI/GCI). The BGI/GCI has been readily adopted by the modelling community as a preferred source of ground cover information at both the paddock and catchment scale.

While the BGI/GCI has been well received by the modelling community, it has been reported to overestimate ground cover by various authors, when compared with visual assessments. The BGI/GCI is calibrated and validated against point intercept ground cover data. Visual assessments of ground cover have been shown to estimate less ground cover, particularly in the middle ranges, when compared with point intercept/BGI/GCI estimates. In general point intercept methods are regarded as more reliable than visual estimates. Typically, modelling frameworks utilise ground cover data using the RUSLE model. In Australia the RUSLE C-factor is typically determined using as: from visual assessments, it is reasonable to expect an underestimate of the RUSLE C-factor when using satellite based estimates. Therefore, to obtain accurate C-factor estimates from satellite data, it may be necessary to adjust for the source of the ground cover data. In addition, the BGI/GCI has recently been replaced by the Fractional Cover Index (fCI). It is not known what the effect the fCI will have on ground cover estimates. This paper looks to investigate both the performance of the new fCI product on ground cover and C-factor estimates and explore the possibility of adjusting C-factor estimates to account for source data that is obtained from satellite, rather than visual field estimates.

Two long-term average dry-season bare ground indexes were compared (BGI/GCI and fCI). Both products were identically masked for cloud, cloud shadow, water and foliage projective cover (FPC) greater than 15%. Total ground cover rasters for each catchment were calculated by taking the inverse of the bare fraction for each raster and were clipped to catchment boundaries. Difference rasters for both total ground cover and derived C-factors were calculated. Additionally, satellite ground cover estimates were adjusted to an equivalent visual estimate by a non-linear conversion function. The adjusted visual estimates were then converted into C-factors (adjusted-fCI). The density distributions and medians for total ground cover, C-factors and adjusted C-factors for both indexes were also calculated. There was very little predicted difference in erosion predictions between the new fCI product and the BGI/GCI. A slightly lower median ground cover value for the fCI did not translate into any appreciable difference in the RUSLE C-factor. The median C-factors for both indexes were typically low for all catchments. The lack of change in the C-factor is attributed to the high levels of ground cover predicted for both indexes, for all catchments. Changes at high levels of ground cover have minimal effect with the Rosewell conversion function. In comparison, the distribution of differences between the BGI/GCI and the adjusted-fCI, shows considerable areas of very high decreases in ground cover and large increases in C-factors. For example, the effect of this adjustment in the Fitzroy was to reduce median ground cover from 75% (BGI/GCI) to 52% (adjusted-fCI) and increase the median C-factor from 0.01 to 0.05. The spatial distribution of these increases also varies, which in itself would affect modelling outcomes. All C-factor estimates were reasonable for rangelands.

The conversion function between satellite and visual estimates relies on an accurate determination of the relationship between visual and objective estimates and there is limited research done in this area. Given that satellite estimates will certainly remain the primary source of ground cover data for modelling purposes, developing a new conversion function with this understanding should be a priority. Further research is required and suggested for determining a more appropriate conversion function.

Keywords: *Ground cover, remote sensing, water quality modelling, Great Barrier Reef*

Monitoring to enhance modelling – A loads monitoring program for validation of catchment models

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Abstract: Diffuse pollutant loads discharged from rivers on the east coast of Queensland have caused a decline in water quality in the Great Barrier Reef (GBR) lagoon. The Reef Water Quality Protection Plan 2013 (Reef Plan) aims to halt and reverse the decline in water quality and enhance the resilience of the Reef. It also provides specific water quality and land management targets to be achieved in order to meet the Reef Plan goal.

Monitoring progress towards meeting Reef Plan targets is measured through the Paddock to Reef Integrated Monitoring, Modeling and Reporting Program (Paddock to Reef Program). The Paddock to Reef Program includes catchment scale water quality monitoring of pollutant loads (total suspended solids, nutrients and pesticides) entering the GBR lagoon. The catchment monitoring is conducted by the Great Barrier Reef Catchment Loads Monitoring Program (GBRCLMP). Monitoring data generated by GBRCLMP provides the point of truth to validate loads predicted by Source Catchment models. Loads generated by the model are used to report on progress towards water quality targets that are published in the annual Reef Plan Report Card.

The GBRCLMP calculates both annual and daily pollutant loads, based on monitoring data for 11 catchments that cover the majority of the Queensland east coast.

Over 8500 total suspended solid and nutrient samples have been collected and analysed since 1 July 2006 and more than 3000 pesticide samples have been collected and analysed since 1 July 2009. This has resulted in more than 250,000 discrete data points. This substantial data set allows for robust load calculations. The load calculations suggest that since 1 July 2006 approximately 80 per cent of the sediment loads delivered to the GBR lagoon originates from the two largest grazing catchments (the Burdekin and Fitzroy catchments). In addition, the Fitzroy catchment delivers over half the total monitored pesticide load to the GBR lagoon during the 5 year sampling period. Whereas the two regions with the highest proportion of sugarcane (the Mackay Whitsundays and Wet Tropics regions) deliver approximately one third with the Burdekin and Burnett Mary regions together delivering approximately a sixth. The other catchments deliver a very small proportion of the total pesticide load.

The loads monitoring program is a key component of the paddock to reef program. Whilst load based monitoring is expensive and challenging it is the fundamental point of truth for model validation.

This paper will summarise the GBRCLMP monitoring data collected since 1 July 2006; demonstrate the role of the GBRCLMP in model validation; outline some key improvements that have been made been; and describe the future direction and focus of the GBRCLMP which will continue to be based on the symbiotic relationship between modelling and monitoring.

Keywords: *Great Barrier Reef, Loads, Monitoring, Validation, Water quality*

Evaluation of Simhyd, Sacramento and GR4J rainfall runoff models in two contrasting Great Barrier Reef catchments

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Abstract: The eWater modelling framework has been used to predict streamflow and pollutant loads across the Great Barrier Reef (GBR) catchments, Queensland as part of the Reef Plan Paddock to Reef program. The Simhyd rainfall-runoff model was initially chosen to simulate streamflow across the GBR due to its extensive use for catchment hydrology studies across Australia, particularly in Queensland. The aim of this study was to determine whether an improved calibration could be achieved with alternative models, and secondly to identify the most suitable model and objective functions for high flow event simulations. Source Catchments was coupled to the Parameter Estimation Software Tool (PEST), to compare the performance of Simhyd to two widely-used rainfall-runoff models available in the Source framework, namely Sacramento and GR4J. Two contrasting catchments were selected with three nested gauging stations in each, with total drainage areas of approximately 10,000km^2. The first is in the upper Burdekin Dry Tropics Region and the second in the Wet Tropics region, both are located in the northern GBR.

Statistical evaluation of the three rainfall-run models found that in Burdekin dry tropics catchment, all three models had a coefficient of determination (r^2) greater than 0.75 and daily Nash Sutcliffe Coefficient (NSE) greater than 0.55 with the exception of a Simhyd result at one gauge. Overall, the Sacramento model achieved the highest r^2 and NSE values. Similarly, all three models have simulated total flow volume ratios (bias) within 20% with the exception being Simhyd at one gauge. Sacramento outperformed the other two models when comparing high flow volume ratios (bias). When simulating middle and low range flows, the GR4J model simulated volume ratios greater than 20% for all sites. In the Wet Tropics catchment, the Sacramento model achieved the highest r^2 and NSE compared to Simhyd and GR4J, although the latter two models achieved acceptable r^2 and NSE values according to the criteria applied in this study. All three models simulated acceptable volume ratios of total flow and high flow in this drier Burdekin catchment.

The Sacramento model also achieved the lowest bias (volume ratio) in the simulation when comparing flow statistics for the three biggest flow events on record in both catchments. Visual assessment of the hydrographs also revealed that Sacramento model simulated the timing and magnitude of peak flow and the shape of recession curves of the large flow events better than the other two models.

The preliminary results from the calibration suggest that the Sacramento model may provide an improved calibration performance over Simhyd and GR4J. The use of Source Catchments coupled to PEST using multiple objective functions also improved calibration statistics over Source Catchment's in-built calibration tool. Future work will look at assessing other objective functions and alternative rainfall inputs to refine high flow calibrations.

Keywords: *Source Catchments, PEST, parameter calibration, objective function*

Author index

A

Abadi, A. 605
Abbasi, B. 755
Abbaspour, K.C. 760
Abbs, D.J. 706
Abdollahian, M. 452
Abell, A.D. 448
Abeynayake, D. 178
Abidin, S. 278, 286, 306
Abraham, J. 337, 341
Abrami, G. 555
Abreu, C.G. 557
Abu-Ajamieh, A.M. 16
Aburumman, A. 501, 502
Adams, G. 414
Adams, R. 762
Addi, K. 324
Adhikary, S.K. 671, 744, 787, 788
Adiyanti, S. 103
Agon, A. 178
Agrawal, M. 321, 637
Ahamed, S. 637
Ahammed, F. 656
Ahmad, M.H. 279
Ahsan, A. 689
Ainsworth, N. 161
Ajami, H. 625
Akartunalı, K. 472
Akbarkhiavi, S.P. 674, 745
Akita, J. 287, 289
Akram, S. 666
Akter, S. 565
Akuraju, V.R. 775
Al Bitar, A. 629
Al-Amin, M. 673
Alankarage, G.H. 734
Albrecht, A. 322, 524, 525, 528
Alcoe, D. 647
Alcorn, M.R. 615
Alharthy, E. 749
Allard, T. 234
Allen, D.E. 294, 295, 296, 297
Allenbach, M. 206, 572
Allgeyer, S. 84
Almeida, A. 170
Altartouri, A. 354
Alvarez-Garreton, C. 776
Alwadiyeh, E.S. 502
Al-yousef, A. 166
Ambrizzi, T. 658
Aminov, P. 422
Amorim, R.S.S. 407
Amran, A. 583
Anbalagan, R. 133
Anderson, P. 226
Anderson, R.W.G. 449
Anderson, T. 358
Anderssen, R.S. 20, 39, 40, 47
André, J. 352
Angelopoulos, N. 139
Anggraini, D. 452
Anticev, J. 275
Anvar, A.M. 218, 219, 220, 221, 222, 223, 224, 225
Anvar, A.P. 218, 223
Anwar, A.H.M.F. 597
Anwar, M.R. 374, 605
Anzooman, M. 803
Apan, A. 594
Appalasamy, S. 328
ApSimon, H.M. 424, 425
Ara, I. 431
Araya, S.G. 432
Araya-Muñoz, A. 183
Arbon, K. 437
Argüeso, D. 700, 701, 703, 704
Arora, M. 609
Arreola, J. 280, 296
Arshad, M. 746
Aryal, J. 169
Aryal, R. 388, 638, 688, 789
Aryal, S.K. 602, 611, 612, 761
Ascough II, J.C. 632
Asher, M.J. 104, 564
Ashworth, P. 582
Aslam, Z. 685
Assoumou, E. 329
Atalifo, T. 716
Athira, P. 603
Atkinson, R. 574

Aubron, C. 99
Aurambout, J-P. 161
Ausseil, A.-G.E. 363, 408
Austin, J.M. 343
Awadalla, M. 195
Aye, L. 604, 771
Aynul, K. 710
Ayre, M. 331
Aziz, K. 590
Aziz, M.A. 667, 668
Azizan, N.A. 279
Azmi, M. 648

B

Babister, M. 678
Bae, S. 453, 454, 456, 457
Bagley, M. 17
Baillie, C. 170
Baird, M. 357
Balamurli, S. 662
Baldock, J.A. 361, 364
Bange, M. 151
Bao, C. 314, 315
Bardsley, W.E. 554, 730, 743
Bari, M. 597
Barkey, R.A. 583
Barlow, K.M. 140, 141
Barma, D. 380
Barnett, S.R. 649, 747
Barreteau, O. 555
Barrett, D. 129, 130, 131, 132, 606
Barrett, T.W. 404, 443, 444, 445
Barry, S.C. 162, 163
Barson, M. 795
Barthelemy, J. 304
Bartolucci, A. 454
Barua, S. 790
Bärwolff, G. 526
Basso, B. 346
Bastian-Pinto, C. 319
Batelaan, O. 770
Bates, B. 52, 591
Bayliss, P. 386
Baynes, T.M. 542, 578
Beaty, M. 578
Beautrais, J.R. 142, 158
Beck, J.D. 236
Beecham, S. 388, 638, 640, 642, 688, 789
Beh, E.J. 37, 448, 451
Bell, R. 579
Bellis, D. 422
Beltrán, F. 305
Belusko, M. 325, 326
Bende-Michl, U. 650
Bender, A. 272, 479
Benger, S.N. 344, 375
Bennet, M.G. 584
Bennett, B.S. 591
Bennett, J.C. 669, 677
Bennier, J. 265
Ben-Tovim, D. 26
Berres, S. 88, 128, 526
Berryman, M.J. 304, 774
Berscheid, A. 246
Bertone, E. 686
Beverly, C. 369, 370, 562, 564
Bhaskar, A. 527
Bhavnagri, B. 18
Bhosale, B. 179
Bi, W. 180
Bian, X. 77
Biarnès, A. 556
Biggs, J.S. 359, 800
Billah, Md. S. 675
Bilusich, D. 245, 252
Bindoff, N. 57
Birch, G.F. 381, 383
Birkin, M. 196
Birzer, C.H. 124
Biswas, F. 650
Blakers, R.S. 618
Bleisch, S. 50
Bloomfield, D. 423
Boatman, N.D. 365
Bodisco, T. 340
Boffey, R.R. 295
Bogomolov, T. 41
Bohnet, I.C. 579
Boland, J.W. 30, 31, 120, 122, 321, 323, 325, 326, 430, 542, 637, 639
Boland, N. 473, 474, 475, 476, 477, 503, 504
Bonte, C. 572
Booth, D. 358
Bordet, A. 387
Bormann, K.J. 700
Borwein, J. 535
Botkin, D.B. 401
Bouckaert, S. 329
Boulaire, F.A. 181, 330

Bovis, K. 725
Bowden, F.D.J. 253, 260, 491, 522, 523
Bowden, J.C. 189
Bowen, D. 511
Bowley, D.K. 260
Box, P. 574
Boyle, J. 460
Braccia, M. 612
Bradhurst, R.A. 97
Bradstock, R.A. 51
Brady, A. 254
Brando, V. 799
Braun, P. 255
Brealey, N. 471
Breedon, M. 184
Bresciani, E. 536
Bridgart, R.J. 207, 212, 213, 547
Bridgeman, J. 693
Brinkman, R. 799
Broderick, N. 256
Brodie, J. 799, 801, 806
Broich, M. 351
Bronders, J. 770
Brook, G. 508
Brooks, P. 339
Brooten, D. 461
Brown, A. 754
Brown, J. 740
Brown, J.A. 478
Brown, R.J. 339, 340
Brown, R.R. 585
Brown, T. 66
Brown, T.J. 246
Bruce, L.C. 390
Bruggemann, R. 429
Brunner, P. 633
Bruno, F. 325
Bryan, B.A. 6, 148, 154, 402, 415, 433
Buhr, C. 387
Bulluss, B. 214
Bunder, R. 475
Buntine, W. 264
Burch, M.D. 643
Burggraaf, V. 158
Burn, S. 712
Burston, J. 548
Burton, M. 56
Busuttil, E. 220
Butler, J. 95
Bye, D. 443

C

Caballero, W.L. 592
Cabot, F. 629
Cacho, O.J. 164
Caffrey, J.L. 456
Cai, G. 337
Cai, J. 134, 136
Cai, W. 641, 644
Caietti-Marin, S. 619
Calanca, P. 409
Calbert, G. 239, 467
Caley, P. 162, 163
Calogine, D. 324
Cameron, M. 550
Campbell, A. 419
Campbell, P. 464
Camporese, M. 403
Candy, B. 725
Cao, T. 512
Car, N.J. 201, 202, 205, 216, 563, 573
Carlesi-Jara, C. 182
Carrara, E. 117, 655
Carreón-Freyre, D. 696
Carroll, C. 796, 797, 802, 804
Carter, J.O. 707
Carvajal, D. 182, 183
Casey, B. 527
Castelletti, A. 619, 620, 624
Cechet, R.P. 49, 58, 72, 73, 83
Cespedes, M. 134
Cetin, L.T. 615
Chaki, T. 744, 787
Chan, F. 273, 274, 277, 282, 299
Chan, W.S. 281
Chang, C.-L. 283, 300, 302, 303
Chang, Y. 188
Chapman, G.A. 404, 445, 446
Chapple, D.G. 355
Charkhgard, H. 474
Charles, A. 657, 716, 721
Charles, S.P. 602, 709
Charney, J.J. 77
Charters, S. 772
Chau, W. 513
Cheema, S.A. 448, 451
Cheeti, A. 461
Chen, J. 738, 756
Chen, Q. 304
Chen, Y. 129, 130, 131, 132, 376, 379, 606

Cheng, A. 99
Cheng, H.R. 421
Cheng, X. 670
Cheng, Y. 749
Cheong, L.M. 50
Cheung, S.C.P. 23
Cheung, T. 749
Chia, J. 711
Chiera, B. 31, 41, 430
Chiew, F.H.S. 709, 717, 761, 769
Chim, L. 245
Chinn, C. 796, 799
Chircop, P.A. 5
Chiu, G.S. 105
Chivers, B. 749
Chong, C.-Y. 301
Chong, D.M. 71, 81
Chong, K.H. 167
Chong, M.N. 789
Choo, K-K.R. 501, 502
Chopin, J. 135
Chow, C.W.K. 685, 688, 693
Chow, W.K. 23
Chowdhury, R. 642
Chowdhury, R.I. 457
Chowdhury, R.K. 791
Christie, K.M. 143
Christie, M. 270
Christopher, P.B. 771
Christy, B.P. 140, 141
Chu, C. 184
Church, J. 716, 721
Cibin, R. 603
Cichota, R. 360, 367, 371
Cichowska, A. 423
Cirocco, L.R. 325
Clancy, L. 151
Clark, S. 107, 605
Clarke, H. 703
Clarke, K. 434, 437, 441
Cleary, P.W. 22, 86
Clement, R. 473, 477
Clifford, D. 361
Clifford, V. 78
Clissold, A. 26
Coelho, C.G.C. 557
Cohen, D. 480
Cohen, W.J. 168
Cole, I.S. 184
Cole, R. 356
Coletti, J.Z. 394
Collier, C. 799
Collins, D. 189, 212, 547, 728
Collins, L. 51
Connor, J.D. 6, 402, 606
Cook, D. 693
Cook, F.J. 42, 389
Cook, M. 508
Cook, S. 587
Cope, M. 64, 65
Cordeaux, C. 497
Corry, P. 505
Costelloe, J.F. 377, 630, 731, 783, 762
Cottrill, A. 716
Courtney-Barrer, B. 564
Coutts, A. 481, 512, 514
Couturier, A. 206, 352, 572
Cowan, T. 641
Cox, J.W. 157
Cox, S.J.D. 574, 654
Cozzi, L. 620
Craig, I. 803
Creighton, D. 19, 489
Cressie, N. 361
Crimp, S. 581
Croft, K.M. 757
Croke, B.F.W. 104, 112, 405, 564, 618
Crone, D.J. 482
Cropp, R. 7
Crosbie, R.S. 765, 777
Crow, W.T. 776, 785
Crowley, G. 579
Cruz, M. 552
Cuddy, S. 129, 130, 132, 214, 634
Cullen, B.R. 147
Cummins, L. 147
Cummins, P. 84
Curnock, M. 579
Curtis, A. 758
Curtis, N.J. 12, 484, 515, 518
Cvitanovic, C. 579

D

Daamen, C. 117, 655, 765
Dafilis, M.P. 89
Dale, A. 579
Daly, E. 152, 403
Daly, R.I. 643
Dam, R. 636

Dandy, G.C. 180, 194, 624, 632, 633, 635, 735, 781, 793
Daniels, P. 542
Das, A. 169
Das, N.N. 786
Das, S. 455
Das, S.K. 362, 621, 671, 744, 787, 788
Dassanayake, K. 775
David, M. 324
Davidson, B. 607
Davy, P. 536
Dawes, W. 765
Dawson, P. 90, 98, 99
de Dreuzy, J.-R. 536
de Haan, F.J. 585
de Hoog, F.R. 40
De Lannoy, G. 629
de Little, S.C. 106, 414
de Nazelle, A. 425
de Visser, G. 229
de Vleeshouwer, N. 672
de Wit, R. 716, 721
De, D. 736
Dean, J.F. 403
Deepak, M. 662
Dekker, A.H. 91, 227
Dekker, G.A. 466
Dennis, S. 158
Denzer, R. 208, 209
Depledge, D. 423
D'Este, C. 171
Devieux, J. 462
Devlin, M. 799
Dexter, P. 258
Dexter, R.M. 257
Dharssi, I. 725
Di Virgilio, G. 355
Diab, H. 247
Dihé, P. 209
Dilek, C. 272
Dillon, P. 692
Ding, L. 749
Ding, Z. 538
Dirks, K.N. 172
Disseldorp, D.A. 726
Djanibekov, U. 416
Doble, R.C. 777
Dods, S. 460
Doherty, J. 539, 618
Doherty, R. 428
Doley, D. 401
Dong, Z. 278
Doody, T. 375
Doole, G. 562
Dougall, C. 797, 802, 805
Dourdet, V. 109
Dowdy, A.J. 52
Dowling, T.I. 345
Dowsett, B. 29
Dresel, P.E. 403
Drikas, M. 693
Drogemuller, R.M. 330
Drusch, M. 629
Duckham, M. 50
Ducrot, R. 555
Duff, T.J. 67, 71, 81
Dumedah, G. 629, 727, 729, 778
Dunn, J. 123
Dunn, M. 580
Dunsmore, R. 49
Dunstall, S. 6, 28, 331, 333, 468, 549
Durrant, J. 612
Dutra, L. 386
Dutta, D. 379, 593, 598, 622, 627, 765
Dutta, R. 169, 170, 171
Dutta, R. 169
Dyack, B. 414, 565
Dye, S. 751
Dyer, F. 405, 565
Dymond, J.R. 408

E

Eady, S. 154
Ebach, M.C. 355
Eckard, R.J. 143, 147
Edraki, M. 650
Edwards, C. 153
Edwards, M.P. 20
Egan, S. 275, 558, 559
Ekström, M. 8, 702, 709
El Sawah, S. 405, 564, 750
Elangasinghe, M.A. 172
Eley, R. 500
ElGindy, T. 331, 468
Elhassan, S. 779
Elliott, S. 440
Ellis, R. 796, 798, 800, 802, 804, 810
Elmahdi, A. 651, 765
El-Zein, A. 589

Engelbach, W. 209
Erbacher, P. 266
Erechtchoukova, M.G. 400, 748
Ernst, A.T. 6, 28, 331, 333, 468, 470, 476, 480
Espada, R. Jr. 594
Evans, J.P. 76, 393, 700, 701, 703, 704, 709, 739
Evans, M.J. 338
Everingham, Y. 708
Evin, G. 764
Ewenz, C.M. 584
Ezzy, G. 597

F

Falzon, L. 244
Faramarzi, M. 760
Faramawi, M.F. 456
Farquharson, R. 361, 605
Farrell, M. 361
Fawcett, R.J.B. 53, 54, 60, 80
Fay, G. 285
Featherston, G. 55
Feikema, P.M. 718
Feinberg, J. 107
Felini, M. 456
Fentie, B. 802, 804
Ferrand, N. 555
Ferrer-Costa, A. 399
Filar, J.A. 537
Fink, M. 406
Finlay, L. 228
Finlayson, J. 605
Firoz, A.M.B. 406
Fischer, C. 406
Fita Borrell, L. 704
Fita, L. 700, 701, 703
Fleckenstein, J.H. 633
Fleming, L. 423
Fleming, N. 647
Fletcher, A. 366
Florec, V. 56
Flügel, W.-A. 406, 577
Foley, J.L. 541
Foliente, G. 492
Foo, C.H. 144
Foo, D. 278, 286
Foss, C. 45
Fouad, M. 453
Fox-Hughes, P. 57
Francis, W. 574
Frascoli, F. 89
Frederiksen, C.S. 665
Frederiksen, J.S. 48, 658, 665
Freebairn, A. 213
Freebairn, D. 369
Frei, S. 633
Freitas, A.C.V. 658
French, I. 49, 58, 72, 83
Frost, A.J. 763, 765
Fry, J. 542
Fu, B. 565, 566
Fu, G. 602, 709
Fuhrer, J. 409
Führer, N. 406
Fujii, A. 291
Fujioka, S. 600
Fukami, K. 600
Fukiharu, T. 288
Furumai, H. 789

G

Gaertner, P. 482
Gailis, R. 98, 99
Gaitsgory, V. 316
Gajaweera, R. 161
Gale, K.R. 795, 796
Galelli, S. 619, 620, 624
Galister, M. 511
Gallant, J.C. 343, 345, 346
Gallant, S. 547
Gallasch, G.E. 469
Gallego, G. 483
Gambolati, G. 696
Gan, H.S. 328
Gandhi, S. 456
Gani, R. 238
Gao, L. 129, 130, 131, 132, 606, 634
Gao, Y. 780
Garanovich, I.L. 229, 259
Garcés, R. 128
García-Flores, R. 145
Garner, M.G. 97
Gato-Trinidad, S. 661
Geard, N. 92
George, B. 604, 607, 609, 753, 775, 784
Gerold, G. 407
Geschke, A. 542

Ghadiri, H. 666
Ghahramani, A. 146
Ghobakhlou, A. 203
Ghosh, N.C. 613
Gibbs, M.S. 434, 616, 624, 735, 781
Gibson, J.A. 551
Gidlow, B. 772
Giełczewski, M. 608
Gill, A. 229, 494
Giltrap, D.L. 363, 371
Gimblett, H.R. 413
Glass, K. 92, 93
Glassborow, D. 255
Godoy, W.R. 506
Goedbloed, A. 619
Golding, B. 423
Gong, X.L. 698
Gongora, M. 796
González, R.M. 499
Gonzalez-Marin, J. 88
Goossens, M. 422
Gossink, D. 234
Gou, C. 335
Gould, J. 282, 552
Gouweleeuw, B. 379
Gowlett, P. 230
Grafton, Q. 565
Grafton, R.Q. 285
Graham, P. 6, 331
Grant, J. 86
Grant, K. 102
Grantham, A.P. 326
Gray, J.M. 446
Gray, R.T. 465
Gray, S. 712
Green, A. 241, 243
Green, G. 647
Green, J.M. 240
Greenwood, P.L. 150
Grieger, D. 237, 513
Griesser, A. 716
Grigg, A. 623
Grigoleit, M.T. 21
Grinham, A. 388
Grisogono, A-M. 260
Groen, L. 749
Grose, M.R. 8, 57, 702
Grozev, G. 275, 332
Gruber, G. 208
Guan, H. 538
Gubernov, V.V. 36
Guillaume, J.H.A. 566, 732, 750
Gunatilaka, A. 242
Gunte, S.S. 613
Guo, H. 421, 527
Guo, P. 219
Guozhu, L. 186
Gupta, D. 33, 320
Guzha, A.C. 407

H

Haddad, K. 595, 596, 599
Hadley, A.L. 263
Haebich, A. 522
Haefele, S.M. 133
Hagare, D. 595, 692
Haines, A. 423
Hajani, E. 673
Hajat, S. 423
Hakendorf, P. 26
Hall, J. 424
Hall, M. 782
Halog, A. 154
Hämäläinen, R.P. 567
Hamilton, S.H. 750
Hancock, G.R. 347
Hansen, A.V. 9
Haque, M.M. 595, 676
Harland, K. 196
Harper, M.L. 543
Harris, R. 57
Harris, S. 66
Harrison, E. 405
Harrison, M.T. 143, 147
Hartcher, M.G. 573, 575
Harvey, D. 256
Hasan M. 405
Hasan, M.M. 112, 733
Hassenforder, E. 555
Hateley, L. 802
Hatfield-Dodds, S. 6, 578
Havlik, D. 209
Hay, T.K.C. 484
He, X. 538
Heal, M.R. 428
Hearne, J.W. 546
Heathcote, A. 475
Hegarty, R. 153
Hegland, M. 39, 43

Heikkilä, A.-M. 209
Heilman, W.E. 77
Held, A. 436
Hell, Th. 208, 209
Hellard, M. 101
Helle, I. 111, 420
Hellicar, A. 171
Hemming, D. 522
Henderson, B. 728
Hendon, H. 657, 716
Hendricks Franssen, H.-J. 629
Herckenrath, D. 539
Hernández, S. 197
Herr, A. 578
Herzig, A. 210, 408
Heseltine, T. 229
Hester, S.M. 164
Heubeck, S. 156
Hewa, G.A. 773
Hickin, J. 220
Hidayat, S. 734
Higgins, A.J. 275, 332, 492, 509, 533
Hilbert, D.W. 579
Hill, R. 579
Hill, S.J. 347
Hilton, J.E. 22, 59
Hinchley, D. 579
Hipsey, M.R. 103, 390, 391, 394, 396
Ho, K.-Y. 308, 309, 312
Hobbs, W.S.R. 515
Hocking, J.S. 465
Hodgkinson, J.H. 581
Hoffmann, P. 705
Hogan, A.B. 93
Holzkämper, A. 409
Horn, M.E.T. 332
Hosking, T. 380
Hossain, I. 687
Hossain, M. 595
Hossain, M.A. 674
Hossain, M.S. 596
Hossain, Q.S. 788
Howard, C.Q. 240
Howden, M. 580
Howden, P.ff. 185
Howlett, P. 525, 534, 535
Hsu, H.-K. 283, 300
Hu, E. 223
Hu, M. 23
Hu, Y. 516, 517
Huang, C. 376
Huang, F. 790
Huang, J. 321
Huda, N. 668
Hudson, I.L. 37, 342, 448, 451
Hudson, S.A. 448
Huggins, R.L. 809
Hughes, J.D. 593, 622, 623, 627, 738, 765
Hughes, L.P. 382
Hui, B.B. 465
Humphrey, G.B. 624, 735, 781
Hung, P.V. 636
Hurt, A. 95
Hüsing, T. 570
Hussain, S. 688
Huston, C. 59
Hutchinson, T.P. 449
Huth, F. 526
Hutson, J. 538
Huynh, N. 35, 304

I

Imai, H. 287, 289
Imteaz, M.A. 661, 667, 668, 674, 679, 680, 687, 689, 745
Inkala, A. 111
Innes, J. 419
Ireland, G. 340
Irrázabal, M. 182
Isenmann, M. 411
Ishak, E.H. 596
Islam, M.A. 457, 788
Islam, S. 485, 486
Islam, S.A. 597
Ivancevic, V.G. 231
Ivanova, K. 469
Iwami, Y. 600, 601

J

Jackson, B.E. 453
Jacob, K. 570
Jafari, N. 331
Jahirul, M.I. 339
Jakeman, A.J. 104, 405, 564, 618, 746
Jakeman, J.D. 732
Jakobsson, Å. 487
Jakovovic, D. 647
James, D. 313

Janssen, S. 10
Jayasooriya, V.M. 792
Jayatilaka, C. 651
Jenkinson, R. 101
Jha, S.K. 736, 737
Ji, F. 703, 704
Jiang, L. 229
Jiang, W. 113
Jiao, X. 694
Jin, H. 728
Joehnk, K. 765, 777
Johnson, F. 719, 720, 733, 739, 741
Johnson, W.T. 231
Johnstone, M. 19
Jolivet, S. 620
Jolma, A. 204, 354, 447
Jones, D. 716
Jones, O. 723
Jones, O.D. 328
Juliano, P. 145
Jupp, D.L.B. 436
Jurdak, R. 100

K

Kabir, A. 652, 653
Kachoyan, B.J. 261
Kajitani, S. 290
Kalinowski, T. 476
Kamarazaman, M. 528
Kamimera, H. 601
Kämpf, J. 540
Kamran, A. 186, 190
Kamruzzaman, M. 638, 640
Kang, S.Y. 458
Kapoor, A. 25
Kapoor, R. 531
Kardel, I. 608
Karim, F. 379, 598, 805, 806
Karim, Md. R. 675
Karimian, H. 221
Karunasekera, S. 242
Katara, C. 425
Kath, J. 564
Katurji, M. 77
Katzfey, J.J. 702, 705
Kaur, S. 503
Kavetski, D. 646, 764
Kawabuchi, K. 292
Kawai, R. 488
Kealy, A. 50
Keatley, M.R. 342
Kebreab, E. 9
Keep, D. 241, 243
Kelliher, F.M. 360
Kelly, B.F.J. 737
Kelly, H. 102
Kelly, J. 489
Kelly, R.A. 564
Kelso, J. 56
Kennedy, M.C. 365
Kent, D. 652, 653
Kenway, S. 542
Kepert, J.D. 53, 54, 60, 61, 80
Kerr, Y. 629
Kessel, A. 423
Khaiter, P.A. 400, 748
Khan, M.Z.K. 114
Khan, U. 625
Khanna, S. 460
Kharazi, M. 173
Khoo, Y.B. 578
Kibria, G. 595
Kiefer, M.T. 77
Kilby, P. 24, 529
Kilminster, K. 390
Kilpatrick, A. 437
Kim, S. 212, 593, 627, 765
Kim, S.S.H. 622, 738
King, D. 148
Kininmonth, S. 351
Kirby, M. 317
Kirkkala, T. 447
Kirono, D.G.C. 583, 588
Kiss, L.N. 490
Klados, A. 276
Klausner, J.D. 462
Klein, T. 409
Kluitenberg, G.J. 44
Kmoch, A. 203
Knapen, M.J.R. 10, 570
Knight, J.H. 44
Kodur, S. 541
Kokic, P.N. 707
Koleva, M.N. 690
Kolikow, S. 149
Kolobov, A.V. 36
Kontoleon, N. 244, 333
Korshin, G. 693
Kosowski, L.R. 262

Kosztołowicz, T. 450
Kotz, S. 586
Kovacs, K. 407
Kovalchuk, A. 133
Kovalchuk, N. 133
Kozan, E. 495, 498, 500, 507
Kragt, M.E. 149
Kralisch, S. 577, 626
Kramadibrata, A.R. 295
Krishnamoorthy, M. 470
Krupp, K. 462
Krysiak, K. 258
Kucharska, D.J. 377
Kulasiri, D. 166, 167
Kuleshov, Y. 121, 657, 716
Kulkarni, A. 25
Kulkarni, S. 462
Kulkarni, V. 462
Kumar, P. 136
Kung, J. 419
Kunkle, B. 459
Kuruppu, U. 676, 683
Kusy, B. 100
Kwak, Y. 601
Kwan, P. 97, 193

L

Lade, S.J. 395, 418
Laffan, S.W. 348, 353, 355
Laga, H. 135, 137
Lam, S.H.M. 421
Lambert, M.F. 591, 628, 645, 646
Landi, S. 270
Lane, J. 542
Lane, P.N.J. 718, 723
Langhans, C. 349, 723
Langston, A. 578
Lappas, P. 23
Laredo, L. 509
Larson, S. 583
Lau, K.W. 578
Lau, R. 711
Lau, W.M. 99
Laugesen, R. 652, 653, 684
Laurenson, Y.C.S.M. 150
Lauret, P. 324
Lautenbach, S. 410, 417
Laux, P. 406
Lavender, S.L. 706
Law, M.G. 465
Lawley, E.F. 435
Lazarova-Molnar, S. 211
Le, B. 653
Le, Q.B. 416
Le, V. 19
Leandowska, K.D. 450
Lee, A. 530
Lee, G. 57
Lee, G.M. 317
Lee, I. 501
Lee, J.H. 383
Lee, S. 64, 65
Lee, S.X. 284
Leemaqz, S.Y. 466
Lehmann, E.A. 711
Lei, L. 691
Leigh, G. 419
Leighton, B. 212, 765
Lemckert, C. 382, 691
Lenzen, M. 542
Leonard, M. 645, 646, 720, 724
Lerat, J. 593, 622, 627, 738, 765
Lesslie, R. 444
Lethbridge, M.R. 543
Levin, S.A. 395
Lewis, A. 436
Lewis, E. 484
Lewis, M.M. 432, 435, 438, 441, 442
Lewis, R. 693
Leys, J. 571
Li, C. 617
Li, C.Z. 187
Li, F. 436
Li, H. 766
Li, J. 73, 113, 115, 358, 739
Li, J.S.-H. 281
Li, L. 628
Li, M. 87, 677, 691, 749
Li, X.Y. 174
Li, Y. 396, 578
Lievens, H. 629
Lilburne, L. 367
Lim, C.M. 334
Lim-Camacho, L. 582
Lin, X.G. 549, 553
Lindesay, J.A. 580
Ling, F.L.N. 168
Ling, S.-Q. 301
Little, L.R. 285, 419

Liu, D.L. 374, 605
Liu, J. 187
Liu, S. 32
Liu, S.Q. 507
Liu, W. 312
Liu, W.J. 187
Liu, Y. 701
Loechel, B. 581
Lokers, R. 10
Lord, S. 245, 252
Love, A. 538
Loveridge, M. 659, 678
Lowe, D.B. 263
Lowell, K. 568
Lu, T-F. 195, 218, 222
Lu, Z. 691
Lucey, A.D. 192
Lui, F. 512
Luo, Q. 151
Luo, X. 45, 318
Luo, Y. 695
Luo, Z. 148, 364, 373
Luoma, J. 567
Luong, L. 16
Luque, S. 411
Luquet, D. 368
Luscombe, R. 495
Lyle, G. 415, 432, 437
Lymburner, L. 118, 436
Lyons, P. 579

M

Ma, J. 35, 749, 774
Maasoumi, E. 303
Macchiavello, B. 557
MacDonald, A. 652, 653
Macdonald, L. 361
Mackay, A.D. 142, 158
Mackay, M. 26
Mackenzie, S. 122
Mackey, B. 385
Macpherson, B. 725
MacRae, C.A.G. 333
Madden, C. 232
Madhivanan, P. 462
Maggi, F. 152
Mahadevan, M. 157
Mahakalanda, I. 751
Maheepala, S. 586
Maheshwari, B. 692
Maheswarajah, S. 736
Mahr, F. 161
Maier, H.R. 174, 180, 194, 624, 628, 632, 633, 635, 735, 781, 793
Mainuddin, M. 622
Maïzi, N. 329
Mak-Hau, V. 472
Makhnin, O. 538
Makino, Y. 188
Makuei, G. 121
Malano, H. 607, 609
Malcolm, W.P. 264, 265, 271
Malekpour, S. 585
Malik, A. 542
Malleson, N. 196
Mangeas, M. 352, 572
Mann, I. 532
Manning, C.J. 266, 469, 491
Manser, P.A. 189, 212
Mapstone, B.D. 419
Marcinkowski, P. 608
Marechal, D. 411
Marian, R. 16
Mariethoz, G. 733, 736, 737
Marinoni, O. 154
Marleni, N. 712
Marlow, D.O. 233, 248
Marquez, L. 492
Marsh, L. 234
Marshall, J. 508
Marshall, L.A. 740
Marshall, V. 438
Martin, D. 196
Martin, K.C. 799
Martin-Clouaire, R. 556
Marvanek, S. 598
Masri, A.R. 339
Mathew, S. 334
Mathews, G. 736
Matthews, K.B. 569
Mattner, T.W. 62, 69
Mayer, D.G. 159
Maynard, J. 801
Mazonka, O. 235
Mazouz, S. 578
McAleer, M. 283, 300, 302, 303
McArthur, L. 121, 122, 123, 125
McAteer, S.G. 236
McBryde, E. 101

McCarthy, M. 165
McCaw, J.M. 89, 92, 94, 95, 102, 464
McCloskey, G. 802
McCosker, K. 796
McCoy, J.A. 75, 82
McDonnell, G. 26
McDougall, K. 594
McFallan, S. 509, 578
McFarlane, D.J. 602
McGowan, B. 504
McGree, J. 458
McGregor, J.L. 705
McInnes, D. 126
McInnes-Clarke, S.K. 445
McIntosh, G.C. 249
McIntosh, P. 716, 721
McIntyre, A. 436
McJannet, D.L. 42
McKay, T. 267
McKenzie, C.R. 290
McKenzie, L. 799
McKeown, A. 100
McKinnon, A. 772
McLachlan, G.J. 284
McLean, J. 415
McNamara, C. 492
McPhee, M.J. 150, 153, 159
McRae, R.H.D. 63, 74
McVernon, J. 92, 95, 102, 464
Mearns, L. 15
Medwell, P.R. 124, 338
Meehan, A. 98, 99
Mehrotra, R. 114, 759
Mekanik, F. 679, 680
Mekhtiev, M.A. 239
Melendez-Vejar, V. 182
Mendes, A. 504
Mendis, P. 771
Mengersen, K. 458
Mercer, G.N. 93
Merlin, O. 629
Merrin, L.E. 378, 754
Merritt, W. 565, 752
Metcalfe, A.V. 640
Meyer, C.P. 64, 65
Meyer, W. 415
Michaela, H. 438
Michalewicz, Z. 532
Miklavcic, S.J. 135, 136, 137
Mikolajczak, A. 411
Miles, E. 716, 721
Mililli, B. 778
Miller, C. 59
Miller, D.G. 569
Miller, K.A. 106
Millikan, J. 237
Mills, G.A. 52, 66, 69
Milne, G. 56
Min, S-K. 641
Mirza, F. 212, 305, 586
Miyashige, T. 291
Moalafhi, D.B. 393
Moghaddam, N.F. 782
Moglia, M. 587, 609
Mohais, A. 532
Mohammadi, A. 630
Mohammadian, G. 537
Moin, N.H. 328
Moise, A.F. 702
Molavi, S. 713
Monch, A. 315
Monerris, A. 726, 729, 780
Monks, I.R. 631
Montillet, J.P. 116
Moon, K. 67
Moon, T. 415
Moon, T.T. 484
Moore, A.D. 146
Moore, C. 539
Moore, D. 49
Moore, H.C. 93
Moore, L.M. 37
Moran, C. 579
Moran, D. 542
Morshed, A. 171
Mortazavi-Naeini, M. 315
Mosley, L. 389
Moslim, N.H. 120
Mpelasoka, F. 433
Mueller, J. 799
Mueller, N. 118
Mugera, A. 149
Mukai, N. 188
Mukerjee, J. 238
Mungkasi, S. 27, 85
Murphy, J.E. 233
Murray, A.W.A. 365
Murray, J. 542
Murray, J.V. 754
Murray, L.M. 108, 361

Murray, N. 213, 563
Musgrove, L. 267
Muthukumaran, S. 790
Muttil, N. 662, 712, 713, 714

N

Nabesaka, S. 600
Nahar, J. 741
Nahavandi, S. 19
Naidu, M.K. 124
Naikar, N. 254
Nakaegawa, T. 657, 716
Nakajima, F. 789
Nam, N.D.G. 636
Namazirad, A. 439
Namazi-Rad, M-R. 304, 439
Namekawa, M. 496
Namoora, H. 334
Narayanan, V. 470
Naser, J. 668
Nasrin, T. 714
Natarajan, N. 335, 336
Navarro, J. 154
Nawarathna, B. 607, 609, 753
Nawata, K. 292, 293
Nazari, A. 28
Nesa, M.K. 455
Neumann, L.E. 583, 587, 588
Neuwirth, C. 155
Neville, T. 267
Newman, J.P. 793
Ng, A.C.Y. 281
Ng, A.W.M. 362, 621, 671, 790, 792
Ng, Y.V. 631
Ngo, T. 771
Ngugi, M.R. 401
Nguyen, D.C.H. 632
Nguyen, K.C. 705
Nguyen, M.N. 587
Nguyen, M-T. 229, 259
Nguyen, T. 306
Nguyen, T.H. 587
Nguyen, V. 238
Nichols, S.J. 414
Nihmei, S. 716
Niizawa, H. 287, 289
Noack, K. 234
Nobrega, R. 407
Nolan, M. 6, 402, 433
Nørlem, M. 391
Norman-Lopez, A. 419
Northey, S. 315
Nose, T. 548
Nott, D.J. 740
Novak, A. 248
Nune, R. 607
Nunes-Vaz, R.A. 245, 252
Nuryani, S. 452
Nuttal, J.G. 141
Nyman, P. 349, 723

O

Obiedat, M. 175
Ochoa-González, G.H. 696
Oddy, V.H. 150
Oh, S. 463
O'Halloran, K. 686
Oishi, Y. 87
Ojha, R.P. 453
Okada, S. 663
Okamoto, M. 133
O'Kane, T.J. 658
Okazumi, T. 601
O'Keefe, C.M. 493
Okello, N. 736
Okruszko, T. 608
O'Leary, G.J. 141
Ollington, R.B. 168
Olsen, T.L. 485, 486
O'Neill, J. 511
O'Neill, K. 125
Orach, K. 418
O'Rourke, W. 497
Orton, T.G. 807
Osborne, N.J. 422, 423
Osbrough, S.L. 665
Ostendorf, B. 11, 431, 432, 435, 437, 438, 441
O'Sullivan, J.J. 794
Otinpong, B. 772
Otterbach, A. 68
Overton, I. 375
Oxley, T. 424, 425
Ozorio, L.M. 319

P

Packett, R. 802
Paevere, P. 275, 332
Pagendam, D. 361
Palmer, A. 806
Palmer, M. 711
Pan, M. 629
Panciera, R. 780, 786
Pannell, D.J. 56
Papageorgiou, L.G. 690
Paraska, D. 391
Paré, N. 556
Parent, B. 133
Parry, H.R. 100, 365, 412
Parshotam, A. 156, 356, 440
Parslow, J. 285
Partington, D.J. 628, 633
Partridge, E. 453
Pash, K. 257
Patch, B. 752
Patrick, M.J. 564
Pattison, P. 96, 101, 244
Pauwels, V.R.N. 629, 672
Paydar, Z. 129, 130, 132
Payne, J.E. 807
Payne, T.E. 544
Peace, M. 69
Pearce, G. 78
Peck, A. 155
Pedram, S. 29
Peel, M.C. 722
Peeters, L. 104, 214, 634, 765, 777
Penman, T.D. 51
Penton, D.J. 212, 213, 214, 765
Perera, B.J.C. 362, 621, 671, 715, 790
Perera, K. 753
Pérez, J.L. 499
Perez, P. 29, 304, 439, 774
Perez-Kuroki, A. 200
Perraud, J.-M. 189, 212, 547, 722, 728, 765
Perry, J. 247
Pert, P.L. 579
Petchey, J. 273
Peterson, T.J. 117, 397, 670
Petheram, C. 598, 717
Petrie, S. 95
Pezzaniti, D. 734, 773
Pham, P.X. 339
Phatak, A. 711
Philp, D.J. 465
Phogat, V. 157
Piantadosi, J. 535, 637
Pickett, T. 214, 634
Pierce, C. 99
Pilkington, C. 731
Pincombe, A.H. 268
Pincombe, B. 268, 272
Piniewski, M. 608
Piotto, J. 257
Piper, I. 241, 243
Pipunic, R.C. 783, 784
Pitaliadda, D. 242
Pitinanondha, T. 263
Pitkänen, H. 111
Pless, D.J. 246
Plummer, J. 126
Podger, G. 214, 634
Podnar, D. 66
Polese, M. 209
Polezhaev, A.A. 36
Pollard, A. 422
Pollino, C.A. 378, 754, 757
Polykarpou, E.M. 690
Pool, M. 545
Poovakka, A.K. 784
Pope, A.J. 413
Poruschi, L 542
Post, D.A. 717
Post, V. 545
Potter, N.J. 660, 717
Powell, R.J. 280, 294, 295, 296, 297
Powell, S.J. 414
Power, R. 550, 576
Prakash, B. 716
Prakash, M. 59, 86, 386, 552
Prakhar, A. 662
Pressey, R.L. 579
Prestwidge, D. 509
Price, C.J. 478
Price, O.F. 51, 70
Pringle, M.J. 807
Pritchard, J. 375
Prudat, G. 521
Pudney, P.J. 322, 325, 326, 524, 525, 528, 534
Pugnet, L. 71
Punt, A.E. 285, 419
Purich, A. 641
Purvis, O.W. 422

Q

Qin, S. 26
Quan, N.H. 636
Quezada, G. 578
Qureshi, M.E. 564, 746

R

Rafique, A.F. 186, 190
Rafter, A. 706
Rahman, A. 171, 590, 592, 595, 596, 599, 659, 673, 676, 678, 683
Rahman, A.S. 599, 673
Rahman, J. 615
Rahman, M. 239, 787
Rahman, M.M. 692
Rainbird, J. 579
Rajesh, S. 469, 518
Ralha, C.G. 557
Ralph, T. 380
Ramchurn, A. 763
Ramesh, D.N. 470
Ramilan, T. 605
Ramsey, D. 163
Randall, L. 795
Rashid, M.M. 642
Rasmussen, P. 119
Raupach, T. 189
Rawnsley, R.P. 143, 147
Read, E.G. 751
Reagle, D. 313
Reale, M. 478
Reddy, R. 752
Reedman, L. 331
Rees, L.L.M. 12
Rees, L.M.L. 515
Rees, R.M. 139
Reeves, C. 498
Regan, D.G. 465
Reinbold, H. 66
Reis, S. 422, 426, 427, 428, 570
Rellier, J.-P. 556
Ren, Z. 275
Renard, B. 764
Renzullo, L.J. 129, 130, 132, 189, 728, 765, 784
Reynolds, C. 542
Reynolds, T. 438
Riccardi, G.A. 614
Rice, P. 731
Richards, R.G. 381, 382, 383, 384, 385
Richmond, M. 250
Ricketts, J.H. 176, 707
Ridley, B. 30
Riedel, F. 215
Riffkin, P.A. 141
Rigterink, F. 504
Riley, M. 703
Rimi, R.A. 675
Rivington, M. 15
Robards, M. 24, 529
Roberts, A. 369, 370, 562, 564
Roberts, C.T. 466
Roberts, P. 790
Roberts, S.G. 27, 85, 87
Robertson, B.L. 478
Robertson, D.E. 114, 669, 776
Robertson, W.S.P. 191
Robins, G. 96, 101
Robinson, B. 369, 550, 576
Robson, B.J. 109, 357, 392
Rocha de Paula, M. 476
Roche, S.E. 97
Rodríguez, J.F. 614
Rolls, D.A. 96, 101
Ronkainen, L. 420
Roosenschoon, O.R. 10, 570
Roozbahani, R. 755
Rouan, L. 368
Roundy, J. 629
Rout, S. 752
Roy, D. 459
Rucinski, C. 552
Rüdiger, C. 648, 729, 782, 786
Rutherford, J.C. 110
Rutherfurd, I.D. 106
Rutledge, D. 210, 399
Ryu, D. 607, 630, 775, 776, 780, 783, 784, 785
Ryu, D.R. 377
Ryu, Y. 775

S

Saarinen, E. 567
Sabel, C. 423
Sabel, C.E. 427
Sacks-Davis, R. 101
Saco, P.M. 614

Saft, M. 722
Saha, G.C. 744
Sahin, O. 384, 385, 610
Sahoo, A. 629
Saintilan, N. 380
Sajeev, A.S.M. 97, 193
Sakata, K. 290
Sallis, P. 197, 203
Salmond, J.A. 172
Salvadore, E. 770
Samarasinghe, S. 166, 167, 173, 175, 177
Samsanov, S. 782
Samsuzzoha, M. 667
San José, R. 499
Sanabria, L.A. 49, 58, 72, 73, 83
Sano, M. 384, 385
Santos, I. 103
Sanz, T. 411
Sapkota, M. 609
Sarker, R.C. 661
Sarran, C. 423
Sathasivan, A. 676
Satoh, A. 496
Saunders, K. 386
Saunders, S.M. 421
Sautter, J. 209
Savadamuthu, K. 615
Savelsbergh, M. 13, 331, 468, 474, 476, 530, 531
Saxena, A. 462
Sayama, T. 600
Scarpa, R. 565
Scarth, P. 808
Schaffelke, B. 799
Schellhorn, N.A. 412
Schepen, A.D. 114, 652, 681
Scherb, H. 429
Schlobinski, S. 208, 209
Schlüter, M. 395, 418, 561
Schmitz, O. 770
Schneider, M.S. 21
Schreider, M. 125
Schreider, S. 123, 125, 126, 755
Schultz, L. 31
Schwandt, H. 526
Scott, C.H. 32
Searle, R. 798, 800
Searson, D.J. 449
Seed, A. 733
Selintung, M. 583
Selitung, M. 588
Senadeera, W. 339
Senevirathne, N. 350
Seppelt, R. 410, 417
Seuseu, S. 716
Sexton, J. 708
Sgarioto, D. 232
Shah, H. 334
Shah, P. 31
Shahumyan, H. 794
Shamakhy, A. 102
Shamseldin, A. 590
Shang, J. 336
Shankar, U. 440
Shanmuganathan, S. 138, 198, 199, 200
Shao, Q. 364, 682, 710
Sharma, A. 114, 119, 393, 609, 625, 664, 712, 733, 739, 759
Sharma, S. 33, 33, 320
Sharma, S.K. 344
Sharmeen, L. 683
Sharp, J. 366
Sharples, J. 117, 655
Sharples, J.J. 63, 70, 74, 75, 76, 82
Shaw, M. 800
Shekh, S. 234
Shelton, K. 657, 716
Shen, X. 307
Sheridan, G.J. 349, 398, 723
Sherman, G. 471
Sherwin, C.B. 349, 718
Shettigara, C. 46
Shevchenko, P.V. 318, 319
Shi, Y. 308, 309
Shin, D. 652, 653, 710
Shin, M-J. 732
Shine, D. 235
Shiono, Y. 496
Shoaib, M. 590
Shokravi, S. 34
Shokri, A. 554
Shrestha, D.L. 669
Shu, Y. 171
Shukla, N. 35
Sia, C-S. 277
Sidhu, H.S. 36
Sidoti, A. 749
Siebentritt, M. 415
Siems, R. 610
Sier, D. 460

Silberstein, R.P. 602, 611, 612, 623
Silburn, D.M. 541, 800, 803
Simmons, C.T. 14, 538, 545, 628, 633
Simons, B.A. 654
Simpson, C. 76, 77, 78
Simpson, J.A. 94
Sims, N. 377
Singh, A.K. 294, 295, 297, 298
Singh, G. 476, 493
Singh, K.P. 453, 454, 456, 457, 459
Singh, R. 274, 282
Singhal, N. 172
Sinha, P. 443
Sinnott, M. 500
Sisson, S. 724
Situ, R. 339, 340
Sivakumar, B. 742, 756, 759
Sivapragasam, C. 662
Skewes, M.A. 157
Skocaj, D. 708
Skvortsov, A. 242
Slade, M. 511
Sloggett, R.J. 47
Smajgl, A. 558, 559
Smethurst, P. 170
Smith, A. 728, 765
Smith, A.D.M. 285
Smith, A.M.A. 465
Smith, C.J. 374
Smith, D. 171, 216
Smith, M. 736
Smith, R.A. 809
Smith, T. 205, 207, 213, 214, 216, 634
Snow, V.O. 360, 367
Soltyk, S. 711
Somers, P. 100
Soulié, J.-C. 368
Sow, D. 749
Sparks, R. 460
Spencer, L. 500
Spillane, M. 261
Spillman, C. 716, 721
Squire, G. 576
Srikanthan, S. 655
Stafford-Smith, M. 578
Stamber, K.L. 246, 551
Standley, P.-M. 579
Stanton, B.A. 269
Starkey, S.R. 751
Steel, J. 161
Steinle, P.J. 61, 725
Steinle, S. 426, 427
Stenson, M.P. 212, 189, 573, 765
Stenta, H. 614
Stephenson, A.G. 549
Stewardson, M.J. 106, 377
Stewart, R.A. 610, 686
Stock, F. 6
Stoddard, S.A. 519
Stolk, J. 532
Stone-Jovicich, S. 583
Stott, K. 369, 370, 562, 564
Stratford, D.S. 754, 757
Strathe, A. 9
Stratton, H. 691
Strauch, M. 410, 417
Strauss, D. 387
Su, C-H. 783, 785
Subhashini, W.H.C. 773
Sudheer, K.P. 603, 613
Sugiura, A. 600
Sullivan, A.L. 59, 549, 552
Summerell, G.K. 571
Summers, D. 437
Summers, D.M. 415
Surendonk, T.J. 5
Suzuki, Y. 663
Swierkowski, P. 495
Szemis, J.M. 635

T

Tailby, D. 229
Takeuchi, K. 600
Talebian, M. 483
Tan, C.S. 328
Tan, K.M. 219, 222
Tan, P. 118, 436
Tanaka, S. 600
Tang, J. 719
Tang, J.-T. 302
Tarnopolskaya, T. 315, 316
Tavoni, A. 395
Taylor, B. 616
Taylor, M. 422
Taylor, M.D. 348
Taylor, R. 229
Teatini, P. 696
Telfer, S. 68, 79
Teng, J. 709, 717, 765, 768

Terhorst, A. 170
Tetlow, M. 256
Tetlow, M.R. 240
Thanh, T.V. 636
Thankappan, M. 436
Thatcher, M. 705
Thayalakumaran, T. 369, 370
Thebaud, O. 419
Theil, P.K. 9
Therrien, R. 633
Thiagarajan, R. 239, 467
Thiruvady, D.R. 480
Thomas, E. 102
Thomas, N. 586
Thomas, T. 613
Thompson, A. 799
Thorburn, P.J. 359, 372, 800
Thorne, J. 444
Thurston, W. 53, 54, 80
Thyer, M. 591, 645, 646, 764
Tian, Z.F. 124, 195, 335, 336, 338, 341
Ticehurst, C.J. 379, 598, 777
Ticehurst, J. 758
Timbal, B. 52, 702, 709
Tjandraatmadja, G. 583, 588
Tolhurst, K.G. 50, 67, 71, 81
Tomer, S.K. 629
Tomlinson, R.B. 382, 548
Tonmoy, F.N. 589
Topp, C.F.E. 139
Topping, C.J. 365
Tory, K.J. 53, 54, 80
Touraivane 206, 352, 572
Towers, I.N. 36, 75
Tramoundanis, D. 270
Tran, D. 37
Tran, H.D. 713, 714
Tran, M. 358
Treadwell, A. 254
Tregoning, P. 116
Trevithick, R. 808
Trivisonno, F.N. 614
Troitzsch, K.G. 560
Tsigklifis, K. 192
Tsui, A.K. 307, 310, 311
Tuck, G.N. 38, 285
Tuke J. 438
Tulau, M.J. 445
Tulbure, M.G. 351
Tung, N.T. 636
Tuomi, L. 111
Turner, D. 441
Turner, R. 444
Turner, R.D.R. 809
Turton, S.M. 579
Tuteja, N.K. 625, 652, 653, 684, 710

U

Udachin, V. 422
Uddameri, V. 689
Ueda, Y. 496
Ugon, J. 542
Uhm, M. 453
Unis, C.J. 551
Usher, S.P. 128
Utting, M. 330

V

van Antwerpen, C. 520
van den Berg, M.J. 629
Van Den Bos, R. 650
van den Briel, M.H.L. 5
van der Hoek, J. 271
van der Linden, L. 643
van der Merwe, M. 546
van der Schaaf, H. 217
Van Dijk, A. 765
van Drie, R. 85
van Leeuwen, J.A. 685, 688, 693
Van Niel, T. 343
van Noordwijk, M. 560
van Randen, Y. 10, 570
Van Veen, E. 422
Vanhatalo, J. 111, 420
Vaze, J. 593, 627, 709, 717, 761, 765, 766, 767, 768, 769
Vears, L. 617
Ventelä, A-M. 204, 447
Vereecken, H. 629
Verhoest, N.E.C. 629
Vermeulen, P. 636
Verweij, P. 10
Vetrova, V.V. 743
Vial, J. 736
Vibart, R.E. 142, 158
Vieno, M. 426, 428
Viet, T.Q. 406
Vigiak, O. 369, 370, 562

Villamor, G.B. 416, 560
Viney, N.R. 765, 767
Vleeshouwer, J. 212, 547, 765
Vlek, P.L.G. 416
Vodicka, R. 247
Vogeler, I. 142, 158, 367, 371
Vogwill, R. 394
Voigt, K. 429
Volk, M. 410, 417
Voltz, M. 556
Vu, X. 525

W

Wagner, W. 785
Waidyarathne, K.P. 177
Wain, A. 53
Waite, M. 256
Walker, J.P. 629, 648, 726, 727, 729, 778, 779, 780, 782, 786
Wall, F. 422
Wallace, R.M. 809
Wallach, D. 15, 372
Walmsley, B.J. 150, 159
Walmsley, T. 270
Walsh, T. 5
Wang, B. 709, 765, 768
Wang, C.H. 578
Wang, E. 127, 148, 160, 364, 373, 374
Wang, H. 187, 694, 695, 697
Wang, K. 312
Wang, P. 96
Wang, Q.J. 114, 669, 677, 681, 682, 710
Wang, W. 312
Wang, X. 578
Wang, Y. 195, 223, 702
Wang, Y-G. 144
Wang, Z. 160
Ward, D. 386
Ward, J. 558, 559
Ward, J.S. 465
Wardell-Johnson, D. 569
Warne, M.St.J. 809
Warren, G. 547
Wascher, D.M. 570
Wasko, C. 119, 664
Waterer, H. 473, 477
Waterhouse, J. 801
Waters, D.K. 541, 796, 802, 803, 804, 809, 810
Watson, J. 229
Watson, K. 215, 217
Watson, M. 650
Wattelez, G. 206, 352, 572
Watts, L.M. 353
Wawra, F. 736
Waycott, M. 799
We, J. 695
Webb, D. 542
Webb, J. 403
Webb, J.A. 106, 414
Webb, M. 54
Webb, T. 367
Webby, B. 327
Weeks, A. 140
Ween, A. 229
Wei, Z. 695, 697
Weir, T. 251
Weiskircher, R. 333
Weiss, J. 161, 165
Welch, M. 193
Weller, E. 644
Wells, S. 415
Welsh, W.D. 761
Wen, L. 380
Werner, A.D. 633, 647
Wesley, I.J. 40
West, J. 542, 578
Westcott, D. 100
Western, A.W. 397, 670, 722, 753, 762, 776, 785
Westra, S. 591, 645, 646, 664, 720, 724, 764
Westveld, A.H. 105
Wethasinghe, C. 117, 655, 684
Whalley, J. 138, 199, 200
Wheaton, K. 521
Wheeler, B. 422
Wheeler, G.E. 75, 82
Wheeler, S. 259
Wheeler, V.-M. 75, 82
Whelan, J.A. 665
Whetton, P.H. 8, 702
Whish, G. 800
White, D.C. 442
Whitford, R. 133
Whitney, S.J. 522
Whittaker, G. 410
Whitten, A.R. 38
Wickramasuriya, R. 35, 439, 774
Wicks, S. 79

Wiedmann, T. 542
Wijermans, N. 561
Wild-Allen, K. 357
Wilkening, T. 50
Wilkinson, S. 805
Willgoose, G.R. 347, 350
Williams, P.B. 253, 272, 523
Williamson, B. 422
Williamson, D. 747
Willuweit, L. 794
Wilson, D.P. 465
Wilson, J.L. 538
Wilson, K. 571
Wilson, L. 702
Wilson, T. 652
Winkler, D. 184
Wise, C. 550, 576
Witing, F. 417
Woldemeskel, F.M. 759
Wong, A. 500
Wong, M. 237
Wood, E.F. 629
Woodman, S. 331
Woods, J.A. 617, 647
Woolard, F. 86, 386
Worledge, D. 170
Wouters, M. 68, 79
Wu, D. 604
Wu, H. 749
Wu, J. 376, 697
Wu, J.X. 310
Wu, J-C. 694
Wu, W. 194
Wu, X. 779, 786
Wu, Y. 160

X

Xing, H. 374
Xu, C. 335, 336, 492
Xu, C.Y. 311
Xu, X. 224
Xue, L. 160
Xue, Y. 697

Y

Yalçın Kaya, C. 43
Yan, W. 617
Yan, X. 695, 697
Yang, A. 765
Yang, H. 760
Yang, J.W. 282
Yang, T. 58, 83
Yang, X. 404, 445
Yang, Y. 698
Yaziz, S.R. 279
Ye, S. 694, 695, 697
Yee, M. 726, 729
Yeoh, G.H. 23
Yi, X. 225
Yilmaz, A.G. 715
Ying, D.Y. 22
Yong, J. 298
Yoo, C. 461, 462, 463
Yorkston, H. 799
Yorozuya, A. 601
Young, J.A. 446
Youngblut, J. 461
Yu, B. 666
Yu, F.L. 187
Yu, J. 574, 654, 698
Yu, K. 116
Yu, Q. 374
Yuen, A.C.Y. 23

Z

Zachary, D.S. 430
Zadeh, H.S. 229, 259
Zafar, S. 448
Zakaria, R. 120, 279
Zaloumis, S. 94
Zambelli, P. 426
Zander, F. 577
Zecchin, A. 174
Zeeshan, Q. 186, 190
Zhang, C. 286
Zhang, H. 686, 691
Zhang, J. 19, 160, 195
Zhang, L. 682, 717, 722
Zhang, X. 130, 131, 538, 606, 810
Zhang, Y.Q. 765, 766, 768, 769
Zhang, Z.Y. 307, 310, 311
Zhao, G. 148
Zhao, K. 100
Zhao, N.N. 187
Zhao, W. 127
Zhao, Z. 160
Zheng, F. 724

Zheng, H.	127, 710
Zhong, S.	77
Zhou, M.	129, 130, 132, 533
Zhou, P.	525, 534
Zhu, J.Q.	698
Zhu, K.	301
Zhu, R.	127
Zhu, Z.	314, 315, 317
Zidikheri, M.J.	48
Zou, Z.C.	553
Zuccaro, G.	209
Zund, P.R.	807
Zwart, A.	40

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