INSIGHT : a framework for determining impacts of changes in land and water policies

Paul Walker[1] and David H White[2]
[1] CSIRO Wildlife & Ecology, GPO Box 284, Canberra, ACT, Australia 2601
[2] ASIT Consulting, PO Box 328, Hawker, ACT, Australia 2614

Abstract CSIRO Wildlife & Ecology is constructing a spatially explicit modelling system capable of exploring alternative land and water policy alternatives against plausible price, cost and climate scenarios for the next 20 years. INSIGHT will be used to identify the likely impacts of land and water policy options on regional economies and structural adjustment. Flowcharts have been constructed for most of the major crop and pasture and associated economic models for commodities produced in the Lachlan River Catchment of New South Wales. This enabled the most important components and interrelationships within these models to be readily identified. The next step has been to construct models at the regional scale that contain the essential elements of the more-detailed point models. The paper describes the progress to date in describing these models, and how they have been integrated into a co-ordinated agricultural crop production evaluation system.

1. INTRODUCTION

CSIRO Wildlife & Ecology, under its Future Resources Program, is developing a spatially-explicit modelling system, known as INSIGHT, to explore land and water policy alternatives in the Lachlan River Catchment of New South Wales. This will enable the likely biophysical and financial impacts over the next 20 years of adopting different policies to be determined.

The primary aim of the INSIGHT system is to provide a capability to evaluate a wide range of economic, social, environmental and land use impacts that could affect large areas [Walker et al. 1996]. It would be able to map and summarise key social, economic and environmental outcomes in annual steps to the year 2020. The need for such a system has been identified through workshops conducted by CSIRO Wildlife & Ecology involving a considerable number of potential stakeholders. These ranged from people in the private sector including farmers and bankers, through government administrators and policy makers, to scientific and economic researchers who specialise in the development of modelling systems and policy analysis [Walker et al. 1996].

This work emulates comparable studies overseas. The Netherlands Scientific Council for Government Policy developed a regional linear programming model, GOAL (General Optimal Allocation of Land-use), to determine the likely consequences of taking different land management policy options that were being prescribed within the European Union to their logical conclusion [van Latesteijn 1993]. The resultant systems framework used relatively simple models for the production of different commodities, these being deemed appropriate to the objectives of the proposed analyses, and able to make best use of existing data [de Koning and van Diepen 1992]. In this way the likely consequences of adopting different policy options were explored.

2. INSIGHT

INSIGHT is a framework for integrating economic and ecological information in a manner that respects the principles that have been developed by economists and ecologists. The vision presented is one of a dynamic modelling system that is spatially explicit and future oriented. Recent developments in systems modelling and in the software used by geographic information systems make it possible to use computer systems to explore future land-use options in a spatially-explicit manner.

Resource management in Australia has moved from an emphasis on examining policy alternatives on a case by case basis to a focus on developing integrated programs that seek the synergies and efficiencies from integration. There are, for example, significant advantages in pursuing dryland salinity, agro-forestry and biodiversity policies simultaneously. There is interest, also, in the temporal sequence of land-use alternatives. Concepts like multiple and sequential land-use are now being explored.

In addition, most State resource management agencies have now assembled significant databases within geographic information systems. There is a need for integration but, as yet, no means to access and process the available data in a cost-effective manner across large areas. While considerable progress has been made in developing integrated models in data rich catchments like the Liverpool Plains [Greiner and Hall 1995], developments that are generally appropriate to a wide range of catchments or regions are few.

INSIGHT is concerned with providing policy makers with timely integrated economic, social and environmental information and with procedures for asking "what if " questions about the likely impacts of policy changes.

2.1 Evaluating alternative land uses

INSIGHT would help users develop scenarios affecting land-use by allowing them to change a range of factors that determine land-use patterns and productivity. It will combine recent developments with GIS-based resource accounting, scenario development, stakeholder involvement and spatio-temporal modelling.

In the first instance, the system would be targeted principally at those who seek to influence or formulate initiatives or policies with regional or state-wide implications.

INSIGHT would:

- identify the spatial implications of these initiatives or policies;
- identify the impact of changes in policies through time;
- have the capacity to evaluate alternative policies by varying a range of measures or instruments;
- provide sufficient information to users so that they are confident that all relevant factors and impacts have been considered; and
- provide mechanisms to compare the impact of alternative policies.

Attention would be given to the time lag between implementation of a policy change and the period when the changes in resource utilisation and condition become noticeable. Because changes in land use will be tracked through time, it will be possible to explore questions about the relative effectiveness of implementing programs at different rates and sequencing changes in alternative orders.

3. PROGRESS TO DATE

Development of INSIGHT is guided by 5 key propositions :

- Adopting a systems view of the environment, including the use of systems thinking and system dynamic models,
- building holistic models that describe interactions among environmental, social, economic and institutional determinants of land use,
- designing models and mechanisms that encourage adaptive management,
- developing guidelines for the use of incentive instruments and mechanisms, and
- building integrated resource information systems using GIS and DSS technologies.

Progress in the development of INSIGHT has focused on two key initiatives:

- A systemic description of current models of crop production, grassland systems, economic systems, degradation and water balance.
- The production of a "demonstrator" version of INSIGHT.

In this paper we describe how we have undertaken the first of these initiatives.

3.1 Model descriptions

Model descriptions are a prerequisite for building INSIGHT. Models were required for the major agricultural commodities produced that would enable their economic and environmental impacts to be determined. Choice of model was undertaken by first examining the range of commodities currently produced in the Lachlan Catchment of New South Wales.

Relevant commodity models were identified, based on searches of the scientific literature [e.g. *Agricultural Systems*; *Environmental Modelling & Software*; White et al. 1993; Hook 1997] and CAMASE, the on-line Dutch register (http://www.agralin.nl/camase/) containing details on over 80 *per cent* of relevant European models for research, education and application in intensively and extensively produced agricultural crops, grasslands, forests, and environments. Other methods included discussions with colleagues and enquiries to the international agricultural models discussion group (AGMODELS-L@crcvms.unl.edu; based at the University of Nebraska) on the internet.

Flowcharts were constructed using the Ventana Simulation Language (VENSIM©) (Ventana Systems Inc.; e-mail: vensim@vensim.com). This makes it very easy to nominate and link the state variables. Draft flowcharts and associated text were forwarded to the relevant author of the particular model for checking.

The next stage involved simplifying the relevant commodity models into minimal models containing what were deemed to be the essential elements for operating these models at a regional scale. These minimal models, for crops, grasslands and rangelands, horticulture including orchards, and agroforestry, are then integrated into the regional Insight model.

4. MODEL OVERVIEW

A wide range of models have already been developed to increase understanding of system behaviour or address management decisions or environmental issues at the farm, catchment, regional and national level [White et al. 1993; Hook 1997]. Many of these were assessed by White and Walker [in press]. These included crop, grassland, rangeland, horticultural, orchard, agroforestry and land degradation models. Only crop and grassland models are discussed in any detail in this paper.

Choice of model inevitably involves compromises, taking into account the objectives of the study, model structure, and the availability of essential inputs.

4.1 Crop models

A number of crop models have been developed, most of these biased towards wheat production. The wheat models of Hammer-Woodruff [H-W, Hammer et al. 1987] and SIMTAG [Stapper 1984], were developed for a sub-tropical climate with summer rainfall and a Mediterranean climate, respectively. They represent examples of successful model applications in two distinctly different climatic regions of Australia. The regional differences are reflected in a key feature of the models, the way dry matter accumulation is calculated. For the mainly water-limited environment of north-eastern Australia, H-W uses the product of transpiration and transpiration efficiency. For the mainly temperature/radiation limited environment in the south-east, SIMTAG uses the product of intercepted radiation and radiation use efficiency.

The conceptual wheat model of O'Leary and Connor [1996] is intermediate in its complexity between the simple models that relate yield to environmental or growth indices, and the more complex models based on precise specification of the physiological basis of growth and yield. It comprises 27 state variables that are grouped within six submodels that deal with water, soil carbon, soil nitrogen, crop biomass, crop nitrogen and phenology. There are also two modules on environment and management. The model introduces new concepts, including coupling Radiation Use Efficiency with Transpiration Efficiency.

There are three wheat models available in APSIM [McCown et al. 1996], including NWHEAT the one in most common use and IWHEAT the most recently developed [Meinke et al. 1998].

4.2 Grassland models

The GrazPlan pasture model of Moore et al. [1997] is now the main pasture growth model for temperate Australia, and is incorporated into the GrassGro DSS. It in part supersedes the DYNAMOF model of Bowman et al. [1993] that worked effectively in Victoria but is no longer supported. Furthermore, there are currently plans underway to have it operating spatially in New South Wales by late 1999 as part of the national *Aussie GRASS* program. This is being done in collaboration with New South Wales Agriculture and the Queensland Department of Natural Resources [Hall et al. 1997].

The GRASP model is an alternative to modelling the semi-arid native grasslands of central and southern New South Wales. Although initially developed for the tropical and sub-tropical grasslands of Queensland, it is being tested in New South Wales, the Northern Territory and Western Australia.

Several grassland models are being compared with GRASP within the *Aussie GRASS* project in terms of their ability to simulate specific pasture communities in the semi-arid, arid, subtropical and tropical lands of Australia. Comparisons are being made with other grassland models: IMAGES, ARIDGROW and SEESAW [Hall et al. 1997].

4.3 Other models

There has been little work on modelling horticultural crops in Australia, a number of the published models being developed in the Netherlands and the U.S.A. These are probably dominated by models of crops grown in glasshouses, in which CO_2, temperature, water, and nutrient inputs can be varied. By comparison, horticultural production in the Lachlan Catchment of NSW is dominated by crops such as asparagus, tomatoes, sweet-corn, wine-grapes and apples grown mostly in irrigated fields. A tomato crop model from the Netherlands [Heuvelink 1995] was deemed suitable as the basis of a horticultural model for use in this study. It is also acknowledged that the importance of water to horticultural crops is particularly great, because most horticultural produce is sold by weight, with water being the major component [Jones and Tardieu 1998].

Trees are common to orchards and agroforestry systems. These are often established on pasture lands, so that sheep can graze between the trees. Apple orchards are being modelled at the University of New England [Hester and Cacho 1997]. Important biophysical interactions between pastures and trees in an agroforestry system in lowland Britain were modelled by Doyle et al. [1986].

5. SIMPLIFYING MODELS

The level of detail in any model is determined primarily by its objectives. A compromise needs to be found between model simplification and the desired level of accuracy.

5.1 Crop model

Crop models overviewed in the previous section, and described in detail by White and Walker [in press], were assessed with respect to their suitability, in part or as a whole, for inclusion in a regional model.

The simplified model has two soil moisture layers, named exploitable and extractable [O'Leary and Connor 1996]. Growth is essentially driven by transpiration until anthesis, which is determined by accumulated temperatures (degree days) since sowing. Grain yield is driven primarily by transpiration post-anthesis, which depends in large part on available soil moisture during that period. Although the parameters will vary between crops, this model should be equally applicable to cereals and oilseeds.

5.2 Temperate pasture model

The proposed model draws on elements of both the DYNAMOF and GrazPlan pasture models. There are two soil moisture layers, an upper layer of about 25 mm in depth and a lower layer down to 1 metre which comprises the root zone of pasture grasses. The upper layer is critical for areas of southern Australia with annual grasses and legumes (clovers, medics), particularly in determining the timing of the autumn break. Pasture species germinate in response to autumn rains, but seedlings die if follow-up rains fail to occur. This signifies a false break.

It is proposed that potential growth rates of pasture for each week of the year be determined by solar radiation and temperature, consistent with the GrazPlan pasture model of Moore et al. [1997]. The parameters would be influenced in part by the pasture mix in each shire, based on data from the national pasture survey (New South Wales). There would be two pasture herbage classes (green and dead), the digestibility of each class varying over time as per Bowman et al. [1993]. Herbage consumption would be based on the estimated stocking rate, that in turn is based primarily on data from NSW Agriculture and the Australian Bureau of Statistics.

5.3 Orchard and other horticultural models

The proposed minimal horticultural model contains elements of the minimal crop simulation model and the tomato crop model. It allows for the production of green biomass and 'fruit', as desired.

6. DEVELOPING A REGIONAL MODEL

The above minimal models are now being integrated into the INSIGHT regional model.

One of the key difficulties in integrating these models is that they have been developed with different objectives in mind, and that their developers tend to come from different disciplines. For instance, criteria that are important in say a grassland system are less important in a cropping system, and vice versa and these criteria have had a large influence on what is included and excluded in such models.

However, INSIGHT is about creating an integrated regional evaluation system; one that integrates information on the stocks and flows of natural resources within the landscape and also from one type of production or crop to another. It is concerned with evaluating the impacts of policy changes on the stock of land and water in a catchment, with identifying the effect of these changes on a wide range of economic indicators; including employment and agricultural production revenue, and their impact on a range of social and cultural indicators.

INSIGHT will provide, not only a wide range of integrated spatial data, but also a tool which policy makers can use to gain insights into the future of natural resource management and use.

7. CONCLUSIONS

This paper describes progress to date on INSIGHT. A key component of this has been the development of the "logic-flow" for a set of relevant models of crop production, economic system and degradation issues.

The next stage is to use these models to develop an integrated land-use evaluation system; one in which a user can ask "what-if" question and identify potential economic, social, and environmental implications. The key to a sustainable rural Australia is to be able to develop insights into the future, to learn from past experience and to adapt to changing circumstances. INSIGHT is a powerful new tool that is being developed to provide these capabilities.

8. REFERENCES

Bowman, P.J., D.J. Cottle, D.H. White, and A.C. Bywater, Simulation of wool growth rate and fleece characteristics of Merino sheep in southern Australia. Part 1. Model description, *Agric. Syst.* 43, 287-299, 1993.

de Koning, G.H.J. and C.A. van Diepen, Crop production potential of rural areas within the European Communities. IV. Potential, water-limited and actual crop production. Netherlands Scientific Council for Government Policy, The Hague, 1992.

Doyle, C.J., J.Evans and J. Rossiter, Agroforestry: an economic appraisal of the benefits of intercropping trees with grassland in lowland Britain, *Agric. Syst.* 21, 1-32, 1986.

Greiner, R. and N. Hall, Integrating catchment hydrology and farm management in a programming model for policy analysis, *Proc. Int. Congr. Modelling and Simulation*, University of Newcastle, 27-30 November, 1995, 1, 166-171, 1995.

Hall, W., K. Day, J. Carter, C. Paull and D. Bruget, Assessment of Australia's grasslands and rangelands by spatial simulation, *Proc. Int. Congr. Modelling and Simulation*, 8-11 December 1997, Hobart, Tasmania, pp. 1736-1741, 1997.

Hammer, G.L., D.R. Woodruff and J.B. Robinson, Effects of climatic variability and possible climatic change on reliability of wheat cropping – a modelling approach, *Agric. For. Met.* 41, 123-142, 1987.

Hester, S. and O. Cacho, A biological model of apple tree production, *Proc. Int. Congr. Modelling and Simulation*, 8-11 December 1997, Hobart, Tasmania, pp. 1091-1096, 1997.

Heuvelink, E., Dry matter production in a tomato crop: measurements and simulation, *Ann. Bot.* 75, 369-379, 1995.

Hook, R.A., Predicting farm production and catchment processes. A directory of Australian modelling groups and models, CSIRO Publishing, Collingwood, Vic., 312 pp, 1997.

Jones, H.G. and F. Tardieu, Modelling water relations of horticultural crops: a review. *Scientia horticulturae* 74(1), 21-46, 1997.

McCown, R.L., G.L. Hammer, J.N.G. Hargreaves, D.P. Holzworth and D.M. Freebairn, APSIM: A novel software system for model development, model testing and simulation in agricultural systems research, *Agric. Syst.* 50, 255-271, 1996.

McKeon, G.M., K.A. Day, S.M. Howden, J.J. Mott, D.M. Orr, W.J. Scattini and E.J. Weston, Northern Australian Savanna's: management for pastoral production in northern Australian savannas, *J. Biogeog,* 17, 355-72, 1990.

Meinke, H., G.L. Hammer, H. van Keulen and R. Rabbinge, Improving wheat simulation capabilities in Australia from a cropping systems perspective. III. The integrated wheat model (I_WHEAT), *Europ. J. Agron.* 8, 101-116, 1998.

Moore, A.D., J.R. Donnelly and M. Freer, GRAZPLAN: decision support systems for Australian grazing enterprises. III. Pasture growth and soil moisture submodels and the GrassGro DSS, *Agric. Syst.* 55, 535-582, 1997.

O'Leary, G.J. and D.J. Connor, A simulation model of the wheat crop in response to water and nitrogen supply: 1. Model construction, *Agric. Syst.* 52, 1-29, 1996.

Stapper, M., SIMTAG: A simulation model of wheat genotypes, ICARDA: Aleppo, and University of New England: Armidale, 1984

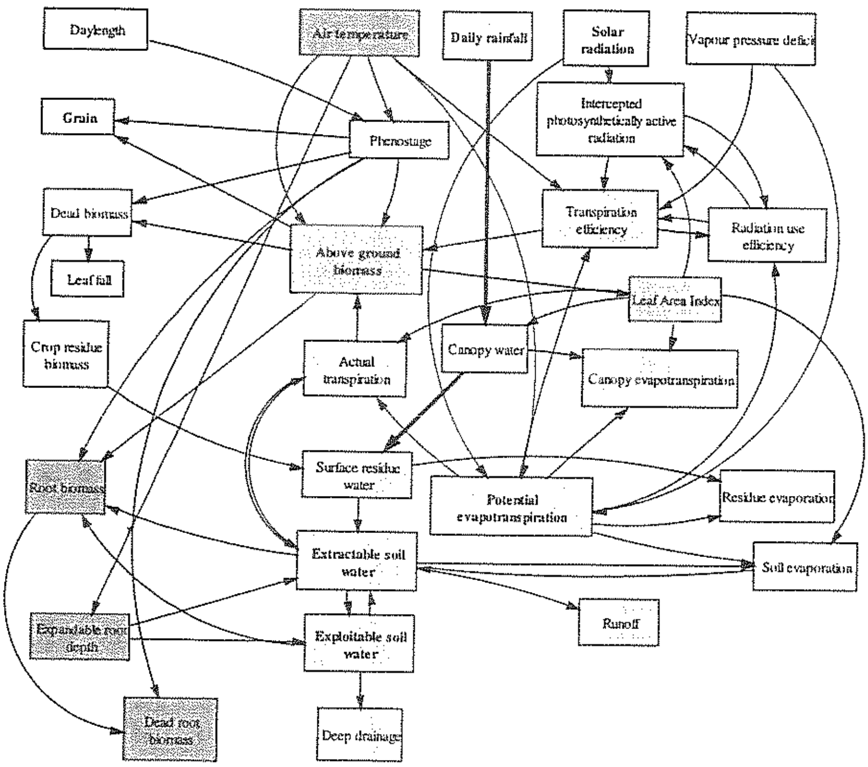
van Latesteijn, H.C., Assessment of future options for land use in the European Community, *Proc. Int. Congr. Modelling and Simulation*, University of Western Australia, 4, 1831-1836, 1993.

Walker, P.A, M.D. Young, R.E. Smyth, and H. Lynch, INSIGHT: a future-orientated and spatially-explicit modelling system for evaluation of land use alternatives, Report from the CSIRO Division of Wildlife & Ecology to the Rural Industries Research and Development Corporation, 1996.

White, D.H. and P.A. Walker, Insights into agricultural models, CSIRO Wildlife & Ecology, Canberra, in press.

White, D.H., S.M. Howden, and H.A. Nix, Modelling agricultural and pastoral systems. In *Modelling change in environmental systems*, edited by A.J. Jakeman, M.B. Beck and M.J. McAleer, John Wiley & Sons Ltd, Chichester, UK, pp. 263-288, 1993.

O'Leary and Connor wheat model



GRASP (GRASs Production) Model