Development of a Spatial Database for Large Scale Catchment Management: Geology, Soils and Landuse in the Namoi Basin, Australia

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Abstract Using the ArcInfo GIS a spatial database is being developed to assist management of a large scale catchment in the Namoi Basin, Australia. The objective is to analyse, map and interpret patterns of rainfall, geology, soils, land use and soil erosion potential in the Namoi Basin with a view to modelling the delivery of suspended sediment and phosphorus at key points in the basin network. Climate, discharge and water quality data to drive and test our hydrologic models are also being incorporated into the ArcInfo dataset.

1. INTRODUCTION

Geographical Information Systems (GIS) are computer-based tools to capture, manipulate, process and display spatial data. They contain both geometric data (coordinates and topological information) and attribute data, that is, information describing the properties of geometrical objects such as points, lines and areas. ArcInfo is a GIS tool for supporting a wide range of techniques of spatial analysis: to create new classes of spatial objects; to analyse the locations and attributes of objects; and, to model using multiple classes of objects and the relationships between them (Goodchild, 1992). Peuquet *et al.* (1993) emphasise GIS as a powerful tool to represent the spatial processes inherent in environmental modelling. Recently, the development of GIS and environmental modelling has been illustrated in a range of studies (eg. Hutchinson and Dowling, 1991; Moore and Grayson, 1991; Elgy *et al*, 1993; Dunn *et al*, 1996; Hallett *et al*, 1996). In particular, Johnston *et al.* (1995) indicated that a multi-attribute spatial database with integrating biophysical and economic modelling was being developed to identify and implement land management strategies for the Liverpool Plains component of the Namoi Basin.

The Namoi is a major tributary of the Murray-Darling system. A range of studies (Jakeman and Murray, 1995; Green and Short, 1995; Crapper *et al.*, 1995; Beecham, 1995; Olley *et al.*, 1996; Crapper, 1996) indicate that there is substantial concern about the impact of land use and irrigation development and the effects of water quality and groundwater pollution in the Namoi Basin. To efficiently and rationally manage water and land resources, there is a need to use GIS for the spatio-temporal analysis of relevant hydrological processes within the Namoi Basin.

The Department of Land and Water Conservation of New South Wales has established a Genamap GIS dataset for the state of New South Wales. That dataset focused on land information at a very large scale. Some of that database in incorporated in ours. The objective of this study is to analyse, map and interpret patterns of rainfall, geology, soil, land use and soil erosion potential in the Namoi Basin. Climate data to drive our hydrologic models and discharge and water quality data to construct and test are also being incorporated into the ArcInfo dataset. The ultimate purpose is to model the delivery of suspended sediment and phosphorus through the stream network in order to be able to determine the relative sources and sinks and how to manage them.

2. DESCRIPTION OF THE STUDY AREA, GEOLOGY, SOILS AND LANDUSE

2.1 Location and Climate

The Namoi Basin, with an area of 41 998 km^2, is located in the Murray Darling Basin system of northwest New South Wales in Australia, with latitude from 29.5S to 32.0S and longitude from 147.0E to 151.5E (Figure 1). There are 407 rainfall stations in the Namoi Basin. The record lengths range from 2-140 years. The distribution of mean annual rainfall varies in the Namoi Basin, ranging from over 1100 mm p.a. in the south east to only 470 mm p.a. in the north west. Most rainfall events are dominated by the summer period. There are three rainfall stations with temperature and 86 stream gauging stations in the Namoi Basin. The streamflow record lengths range from over 100 years down to 5 years.

2.2 Geology

The Namoi catchment lies within a region of geological complexity and diversity and includes Cainozoic volcanics, a section of the Great Artesian Basin including the Gunnedah sub-basin, and the Oxley-Surat sub-basin, and parts of the central and western zones of the New England Fold Belt.

The New England Fold Belt comprises an eroded mountain range bounded on the south and west by border thrust fault systems. The central zone consists of moderately to highly deformed Silurian to Permian rocks which increase in the degree of deformation from west to east. The basement rocks include phyllites, cherts, jaspers and greywackes with interbedded basic volcanics. These are overlain by Carboniferous shallow water marine sediments comprising mudstones, sandstones, limestones, conglomerates and tuffs with interbedded andesites and rhyolites. These rocks are intruded by the New England Granitic Batholith which extends from the vicinity of Tamworth to the Queensland border region, with dominant granitic types being adamellite and granodiorite (Voisy, 1969).

The intrusions generally possess clearly defined contacts and metamorphic aureoles comprising durable hornfels. Basic hornfelses occur, for example, in the Moonbi-Kootingal area, where the Moonbi Adamellite intrudes the Woolomin jaspers and interbedded basic volcanics (Chappell, 1969; Wilkinson, 1969).

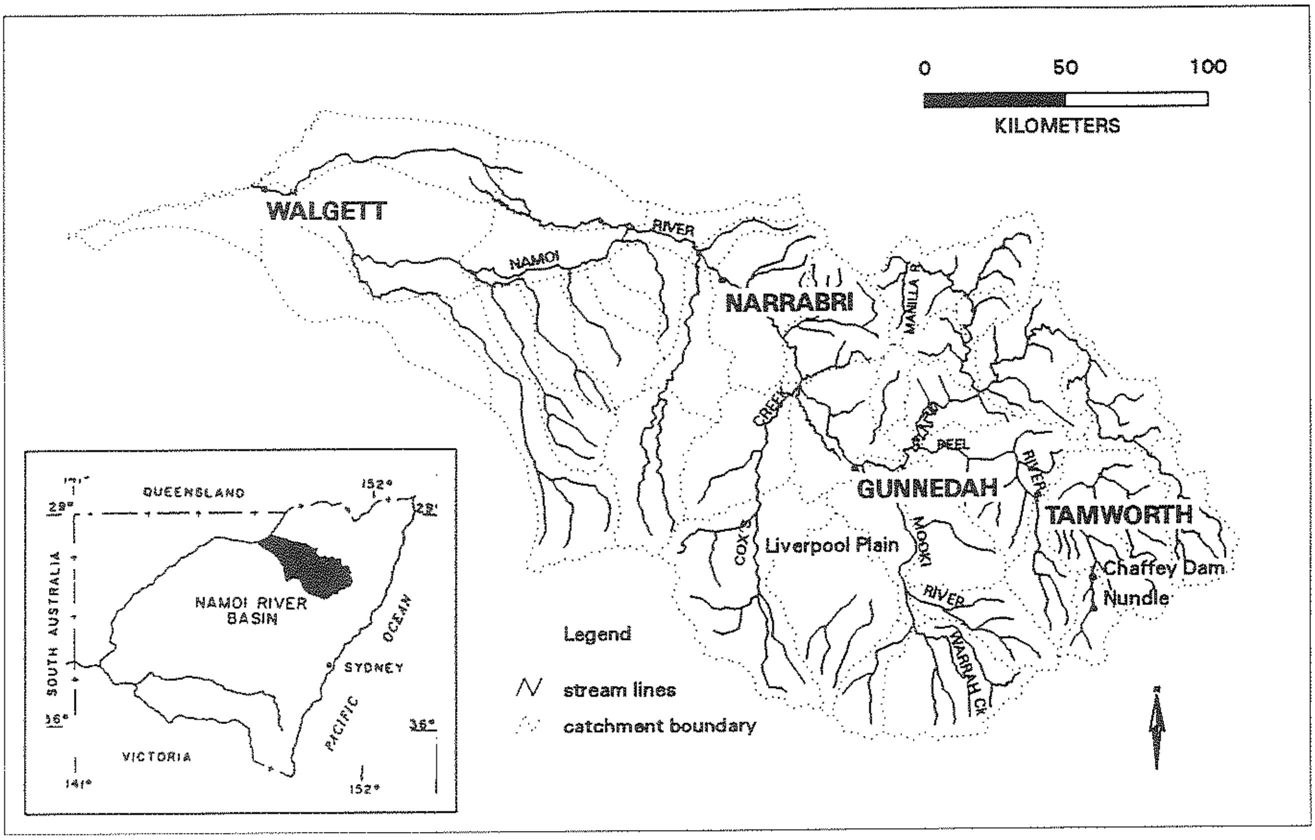

Figure 1: The location of the Namoi basin.

The western zone of the New England Fold Belt is bounded to the east by the Great Serpentine Belt and to the west by the Hunter-Mooki Thrust Fault System. These structures define a major lineament, trending north-northwesterly, which divides the Namoi Basin from the catchment boundary south of Nundle through Tamworth to the northern catchment boundary. The Serpentine Belt is a nearly continuous belt of serpentinites and ultramafic intrusives which is truncated by the Moonbi Adamellite and Inlet Monzonite at Attunga and reappears south of the Peel River where, in the Bowling Alley - Nundle area, the rock is intensely sheared. The Hunter-Mooki Thrust Fault System is a complex system of faults which separate the gently dipping beds to the west from the tightly folded and faulted strata of the Great Dividing Range (Woodward, 1995). The basement rocks of the western zone are composed of Ordovician and Silurian limestones, shales, greywackes and spilites overlain by a succession of Late Devonian to Carboniferous sediments including greywackes, conglomerates, sandstones, shales and breccias.

The structural margin between the New England Fold Belt and the Great Artesian Basin extends from Narrabri through Gunnedah to Murrurundi. To the west of this boundary lie two sub-basins: the northern extreme of the Sydney-Bowen Basin, called the Gunnedah Basin, and the Surat- Oxley Basin. The Gunnedah Basin, which is not hydraulically connected to the Great Artesian Basin, comprises Permian-Carboniferous basement rocks as basalt, acid volcanics, tuffs, and tuffaceous sediments with local, interbedded lenses of freshwater sediments comprising sandstones and conglomerates. Overlying these rocks are a succession of Permian freshwater sediments consisting of conglomerate, lithic sandstone, shale and economic coal seams, the latter forming the Northwestern Coalfields of Willow Tree, Werris Creek, Gunnedah and Narrabri (Tadros, 1988).

Within the Great Artesian Basin, lie the Gunnedah Basin and the Oxley-Surat Basin are separated by the Jurassic Garrawilla Volcanics which outcrop in the Mullaley district as olivine basalt, trachyte and dolerite. Jurassic sediments outcrop extensively in the Oxley-Surat Basin, comprising silty sandstone, mudstone, conglomerate, carbonaceous shales and minor coal of the Purlwaugh Formation, which exhibit a maximum thickness immediately north of the Liverpool Ranges in the Tambar Springs district. These rocks are overlain by the Pilliga Sandstone which consists of a coarse, quartzose sandstone with lenses of conglomerate.

In the western part of the Namoi catchment, the Pilliga Sandstone is overlain by a sequence of shales and siltstones of the Rolling Downs Group. These rocks outcrop as isolated ridges within broad depositional plains comprising Quaternary and Tertiary unconsolidated sediments.

The youngest rocks in the Namoi catchment are represented by Cainozoic extrusive volcanics which outcrop extensively and include basaltic lavas and associated intrusives in the Hanging Rock area, the Nandewar Ranges, the Liverpool Ranges, the Warrumbungles, the small outcrops at Keepit and the teschenites at Mullaley, Gunnedah, Goonoo Goonoo and Nundle.

At these locations, a diverse range of basaltic and associated rocks occur as flows, sills, plugs and dykes. Whilst some areas may represent dissected remains of shield volcanoes (Nandewar Ranges), other volcanic landforms represent pyroclastic extrusions and ash flows, giving rise to cinder cones, plugs, domes and unlithified ashflows. In the Mullaley-Tambar Springs district over 30 trachytic centres of extrusion have been identified suggesting quiet extrusion of lava interrupted repeatedly by a series of explosive eruptions. The original flow tops of these extrusions have been eroded to form a Miocene peneplain surface from which resistant domes, cones and crags rise.

2.3 Soils

The distribution of the soils of the Namoi Basin is a function of geology, topography and climate. Broadscale imagery of the basin indicates the close relationship between geology and soils (Figure 2).

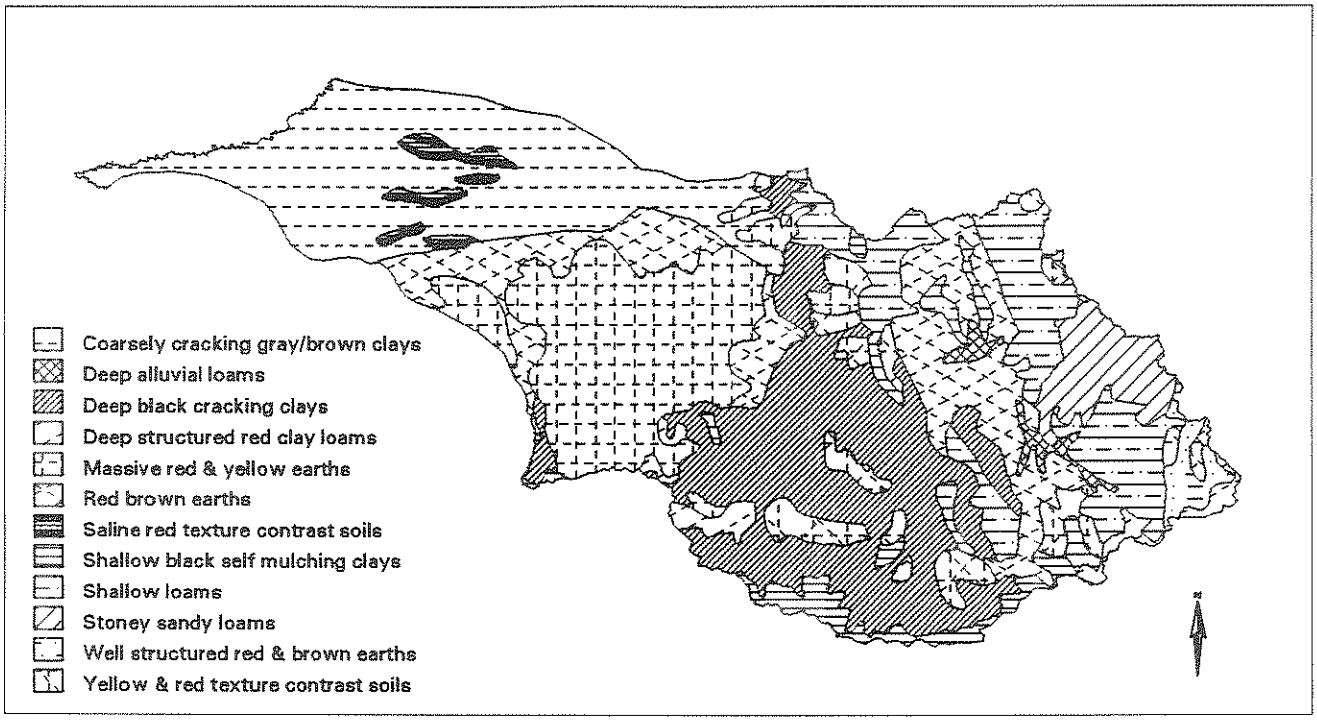

Figure 2: Broad soil types for the Namoi basin from Arc/Info database (source: Genamap database of NSW,DLWC)

The upper catchment, characterised by complex geology and deeply weathered parent material, has a wide range of soils. Soils associated with the metasediments include lithosols and shallow loams on crestal and mid slopes with red and yellow texture contrast soils in lower topographic positions. The sediments within the Hunter Mooki Thrust Fault System are associated with lithosols and solodised red brown earths, and with red and yellow solodic soils on some lower slopes. These soils are highly erodible as a function of their clay mineralogy and poor structure and inherently unstable in terms of both shear failure and erosion. Alluvial fan deposits, developed from transported soil material originating from the Hunter Mooki Thrust Fault System, comprise red brown earths (Donaldson Planning and Management Services, 1996).

Weathering and erosion of the Tertiary basalts of the Liverpool Ranges, which define an arcuate boundary to the south of the catchment, have formed the highly fertile black cracking clays of the Liverpool Plains. Basaltic residual soils are heavy textured kraznozems and chocolate soils grading to euchrozems and red, grey and black cracking soils in the drier parts of the western slopes. Further north, soils associated with the acid volcanic rocks of the Nandewar Plateau include fertile black cracking clays, brown earths and red and yellow texture contrast soils.

The Pilliga Sandstone has weathered to form coarse textured, porous soils with low fertility. These comprise massive red and yellow earths, with hard setting red alkaline soils in the vicinity adjacent to the Namoi River in the Narrabri/Wee Waa districts, which are associated with surface scalding.

The depositional plains to the west of Narrabri comprise very thick sequences of alluvium as grey and brown cracking clays and loams with poor structure and moderate fertility.

2.4 Landuse

The Namoi catchment is a highly productive agricultural and pastoral area with a diverse range of landuses including dryland and irrigated cropping, sheep and cattle grazing, dairying, cattle feedlots, pigs, poultry and urban/residential (Donaldson Planning and Management Services, 1996)

Cropping is practised over approximately 25% of the catchment, centred on the Narrabri and Gunnedah Shires with other significant areas occurring in the Walgett, Quirindi and Parry Shires. The dominant winter crops are wheat and barley which are grown in the Gunnedah-Tamworth districts. In areas with climatic and/or soil constraints small areas are cropped to oats, triticale and cereal rye. Other grains and legumes grown in rotation with wheat and barley include chickpeas, faba beans and canola whilst speciality crops with limited production include linseed, lupins, field peas and safflower. The dominant summer crops are sorgham, sunflowers and cotton. Crop requirements include high soil fertility, good soil moisture and high summer rainfall. Therefore, these crops are distributed in the higher rainfall areas east of Narrabri, particularly in association with the grey cracking clays. However, the distribution of cotton is limited to the south of the Namoi catchment by lower temperatures.

Approximately half of the Namoi catchment is grazed, with sheep being more significant in the tablelands (fine merino production and fat lambs), upper slopes (fat lambs and wool with some constraints applied by soil type and rainfall) and in the western sections of the catchment on the depositional plains downstream of Narrabri (wool). In the tablelands beef and sheep are run together, with the proportions being defined by wool commodity prices. In contrast, beef grazing is often the main farming enterprise on the northern slopes, whilst on the plains, cattle are a component of mixed grazing and cropping. Variable climatic conditions have initiated a trend towards opportunistic feedlotting on large holdings on the plains where farmers can optimise economic benefits provided by the beef and grain markets.

Intensive agricultural industries in the region include cattle feedlots, piggeries, poultry farms and dairying. Large feedlots are located at Caroona, Quirindi and Bective with smaller feedlots scattered throughout the catchment. A number of small to medium piggeries are located in the Narrabri, Gunnedah and Tamworth areas, whilst dairying is limited to the higher rainfall areas along the alluvial flats associated with the Peel, Upper Namoi and Manilla Rivers (Figure 1). The Tamworth area is the site of the highest poultry production outside the Sydney Metropolitan area, with an annual turnover of ~ 4 million birds.

The agricultural, pastoral and mining industries in the catchment are serviced by a number of major rural centres and towns including Tamworth, Gunnedah, Narrabri, Boggabri, Coonabarabran and Walgett.

The majority of the study area is used for grazing, whilst cropping dominates all the flatter country. There are 49.3% of native or improved pasture (20,708 km^2), 23.2% of grain, fibre or fodder cropping (9,741 km^2), 24.9% of forest land (10,468 km^2), 2.1% of irrigation (882 km^2), 0.2% of river, creek, lake, or swamp (83 km^2), 0.1% of mining, rock, roads, etc (32 km^2) and only 0.2% of urban (84 km^2) in the Namoi Basin (Donaldson Planning and Management Services, 1996).

3. DATASET DEVELOPMENT

GIS data resources for the Namoi basin were based on field collection, aerial photography, the Genamap dataset, Pinneena (1996) and Metaccess (1995). Field data for stream water quality are being used as an input to the ArcInfo GIS (Figure 3). The dataset for erosion history was digitised from aerial photography dating from the 1960s to the 1990s for Cox's Creek catchment, and from the 1940s to the 1990s for the Warrah Creek catchment. The scales for these photographic runs range from 1:80 000 to 1:18 000. The Genamap dataset includes spatial data of terrain, geology, land use cover, soil type, soil erosion, and land management for the total basin. The scales for these datasets range from 1:1 000 000 to 1:5 000. In order to make local water resource management for the total Namoi basin consistent with regional management, classification of datasets for land use, terrain, geology, cover, land management and soil erosion for the Namoi Basin were acquired from the Department of Land and Water Conservation of New South Wales. Pinneena and Metaccess were used to develop the hydrological and climate dataset, respectively. Whilst the maps generated from these datasets are useful at a subcatchment to regional scale, it should be noted that they are limited for local scale applications.

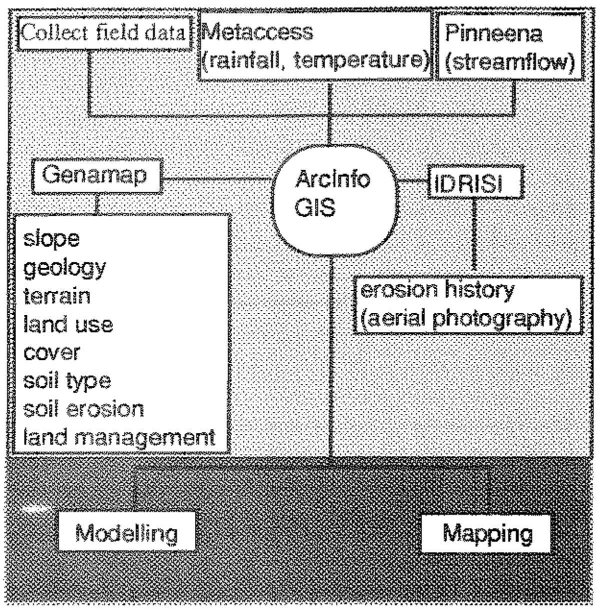

Figure 3: Flow diagram of the processes of dataset development

Dataset development involves the following:

- The ArcInfo GIS by ESRI was selected as the GIS software for this study due to its capability for cross analysing vector and raster datasets, and has been implemented with the SUN SPARC station platform;
- GXFARC software by ESRI Australia Pty Ltd was used to convert vector data from Genamap to ArcInfo;
- IDRISI was used to digitise the aerial photo interpretation;
- AML of ArcInfo was applied in the spatial database, e.g. database (point, line, and polygon) creation and classification;
- Topogrid was used to develop the digital elevation model;
- Arctools and AML were used for map projection and mapping; and,
- The climate dataset was incorporated with streamflow to model hydrological behaviour.

The data format of points, lines and polygons of the spatial dataset for the basin is shown in Table 1.

Table 1: Data format of points, lines and polygons for the Namoi Basin spatial database

Coverage	Description	Feature	Scale
stream line	line	basin	1:250000
rainfall station	point	basin	
gauging station	point	basin	
slope	polygon	basin	1:50000
terrain	polygon	basin	1:50000
cover	polygon	basin	1:50000
soil	polygon	basin sub.	1: 1000000 1:50000
landuse	polygon	basin sub.	1:50000 1:5000
erosion	polygon line line	 basin sub.	 1:250000 1:5000
farm dams	point	sub.	1:5000
DEM	grid	sub.	1:5000

All data layers were transferred into a uniform coordinate system to facilitate subsequent analytical procedures. Adequate visualisation of the currently available digital information was achieved through high quality maps. The map production process has also been automated and is easily adapted to allow dataset enhancements.

Using these datasets as a basis, there were several methods available for the Namoi Basin mapping:

- Total basin mapping identified areas with specific attributes;
- The subcatchment dataset is being used to model impacts of climate and hydrological processes;
- The subcatchment dataset also provided historical information on erosional responses to landuse/land management changes with implications for future management practices.

The evidence indicates dynamic changes of land use during given time series. Streams, erosion gully networks, rills, landcover and land management have been mapped and digitised onto GIS using a number of aerial photographic time slices. A spatial dataset of subcatchments (eg. Warrah creek) has been used to: measure temporal and spatial changes in the fluvial and gully networks, and landuse and land management practices; to assess the changes in the connectivity of gullies to streams; and, to identify channel responses to hillslope erosional process (Beavis *et al.*, 1997).

Jakeman *et al.* (1997) describe how these databases are being used in a modelling framework to predict suspended sediment and nutrient delivery and concentrations throughout the basin, the influence of climate and land use.

So far, the development of the spatial database has concentrated on the specific processes described above (data collection, modelling, analysis and mapping) to meet part of the project requirements. It should be noted that data resources for geology adapted from the Genamap dataset are too coarse at present and will need further development. In the future, the main theme will be to develop an integrative and interfaced regional GIS for local catchment management applications.

4. REFERENCES

Beavis, S., L. Zhang, J. Evans, A.J. Jakeman and D.I. Smith, Impacts and Implications of farm dams on catchment hydrology, *Proc. International Congress on Modelling and Simulation*, MODSIM 97; A.D. McDonald *et al.* (eds), University of Tasmania, 8-11 Dec 1997.

Beavis, S., A.J. Jakeman, L. Zhang and S. Gray, Erosional history of selected upland subcatchments in the Liverpool Plains, New South Wales, *Proc. International Congress on Modelling and Simulation*, MODSIM97; A.D. McDonald *et al.* (eds), University of Tasmania, 8-11 Dec 1997.

Beecham, R. Patterns of spatial and temporal variability of factors affecting Nutrient export from Chaffey Dam Catchment. *Proceedings International Congress on Modelling and Simulation*. MODSIM95, P. Binning *et al.* (eds.), The University of Newcastle. 1: pp 183-187, 1995.

Chappell, B.W., Granitic intrusions from the southern end of the New England Batholith. In G.H. Packham, (ed). *The Geology of New South Wales, J. Geol. Soc. Aust.*, 16, 278-285, 1969.

Crapper P.F, P.M. Fleming and J.D. Kalma, Seasonal Rainfall Anomalies and the Level of Lake Goran. *Proceedings International Congress on Modelling and Simulation*. MODSIM95, P. Binning *et al.* (eds.), The University of Newcastle. pp 207-21, 1995.

Crapper P.F., Sediment and phosphorus sources and fluxes in the Murray Darling. Liverpool Plains and Land Management Committee Workshop titled "Progress in catchment management: an update of research in the Liverpool Plains" Gunnedah, 17-18 September 1996, pp 41-43, 1996.

Donaldson Planning and Management Services, Namoi Community Catchment Plan Stage 1: Situation Statement, March, 1996.

Dunn, S.M., R. Mackay, R. Adams and D.R. Oglethorpe, The hydrological component of the NELUP decision-support system: an appraisal. *Journal of Hydrology*, 177, 213-235, 1996.

Goodchild, M.F., Geographical information science. *International Journal of Geographical Information Systems*, 6, 31-45, 1992.

Green, T.R. and D.L. Short, Analysis of Flow and Preliminary Estimates of Phosphorus Loads in the Namoi Basin, NSW, Australia. *Proceedings International Congress on Modelling and Simulation*. MODSIM95, P. Binning *et al.* (eds.), The University of Newcastle. pp 172 - 177, 1995.

Hallett, S.H., R.J.A. Jones and C.A. Keay, Environmental information systems developments for planning sustainable land use. *Int. J. Geographical Information Systems*, 10(1) 47-64, 1996.

Hutchinson, M.F. and T.I. Dowling, A continental hydrological assessment of a new grid-based digital elevation model of Australia. *Hydrological Processes*, 5, 45-58, 1991.

Jakeman, A.J., T.R. Green, C.R. Dietrich, L. Zhang, S. Beavis and P.F. Crapper, A modelling framework for erosion, sediment and nutrient transport from catchment to basin scale, *Proc. International Congress on Modelling and Simulation*, MODSIM97; A.D. McDonald *et al.* (eds), University of Tasmania, 8-11 Dec 1997.

Jakeman, A.J. and A.S. Murray, Sediment and phosphorus fluxes and sources in the Murray-Darling Basin: Liverpool Plains and eastern Namoi basin. Riverine Environment Research Forum. 4-6 October, 1995. Attwood Victoria, 1995.

Johnston, R., K. Abbs, R. Banks, S. Donaldson and R. Greiner, Unique mapping areas as the basis for integrating biophysical and economic modelling in the Liverpool Plains, *Proceedings International Congress on Modelling and Simulation*. MODSIM95, P. Binning *et al.* (eds.), The University of Newcastle, pp 150-154, 1995.

Metaccess, v1.0, Produced by CSIRO, Australia, July 1993.

Moore, I.D. and R.B.Grayson, Terrain-based catchment partitioning and runoff prediction using vector elevation data. *Water Resources Research*, 27, 1177-1191, 1991.

Peuquet, D., J.R. Davis and S. Cuddy, Geographic information systems and environmental modelling. *In Modelling Change in Environmental Systems*, A.J. Jakeman *et al.*(eds), Wiley: Chichester, pp 543-556, 1993.

Pinneena, Version 5, Produced by Department of Land and Water Conservation, New South Wales Government, Australia, June, 1996.

Tadros, N.Z., Structural subdivision of the Gunnedah Basin, *Australian Journal of Earth Sciences*, 73, 1-20, 1988.

Voisey, A.H., The New England region. In G.H. Packham, (ed), *The Geology of New South Wales, J. Geol. Soc. Aust.*, 16, 227-310, 1969.

Woodward, N.B., Thrust systems in the Tamworth Zone, southern New England Orogen, New South Wales, *J. Geol. Soc. Aust.*, 16, 42, 107-117, 1995.

Wilkinson, J.F.G., Intrusive rocks: the New England Batholith. In G.H. Packham, (ed), *The Geology of New South Wales, J. Geol. Soc. Aust.*, 16, 271-278, 1969.