Jul 1st, 12:00 AM

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Integrated Water Quality Modelling: Ben Chifley Dam Catchment, Australia

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Abstract: This paper describes an integrated hydrologic, stream sediment and nutrient export modelling system. The modelling system is designed to simulate catchment-scale land and water management activities in the Ben Chifley Dam Catchment (BCDC). The dam has experienced problematic blue-green algal blooms over the past decade. The aim of the modelling is to examine management scenarios designed to reduce nutrient and sediment delivery from the BCDC. This paper describes the framework of the system along with brief description of each of the various components. The innovation of the modelling system is the integration of otherwise separate modelling approaches. The output of the project will be methods to focus both on-ground ameliorative action at specific sites and encourage sustainable management practices more broadly in the catchment.

Keywords: Integrated modelling; Nutrient management; Model framework

1. INTRODUCTION

This paper describes an environmental modelling system under development for the Ben Chifley Dam Catchment (BCDC), Australia. The modelling system is designed to simulate land and water management activities within the catchment. The model integrates hydrologic, stream sediment and nutrient export models to enable the development and evaluation of management scenarios designed to reduce nutrient and sediment delivery to the dam. This paper describes the framework used to construct the integrated model, and reports on current progress.

Over the past decade the Ben Chifley Dam has experienced frequent and problematic blue-green algal blooms [Tooth unpublished report]. Reduction of nutrient delivery to the dam is one of the primary management options available to limit the frequency of algal blooms. Tools are required to focus both ameliorative on-ground action at specific sites and to encourage sustainable management practices more broadly in the catchment. The development of the modelling system described here is a major component of a long-term project that includes catchment monitoring, and links with a study investigating the in-storage dynamics of the Dam.

2. CATCHMENT DESCRIPTION

The BCDC is an upland catchment of the Macquarie River, part of the Murray-Darling Basin of south-eastern Australia. The BCDC has a total area of 985km^2 and is the primary source of potable water for the city of Bathurst located 20km to the north. The catchment has a total population of approximately 700; Rockley and Black Springs are the only notable population centres within the catchment. Figure 1 shows the location of the BCDC and highlights the drainage network of the catchment.

The BCDC is used predominantly for the extensive production of sheep and beef cattle. Grazing occurs on both native and exotic pastures. Approximately 14% of the catchment is forested, with commercial forestry plantations (almost exclusively *Pinus radiata*) covering the majority of this area, the remainder of the forested area is

remnant or regrowth native forest. Less than 1% of the catchment used for cropping. Over recent years there have been steady increases in wine grape production, however, viticultural areas cover only a minor proportion of the total catchment area.
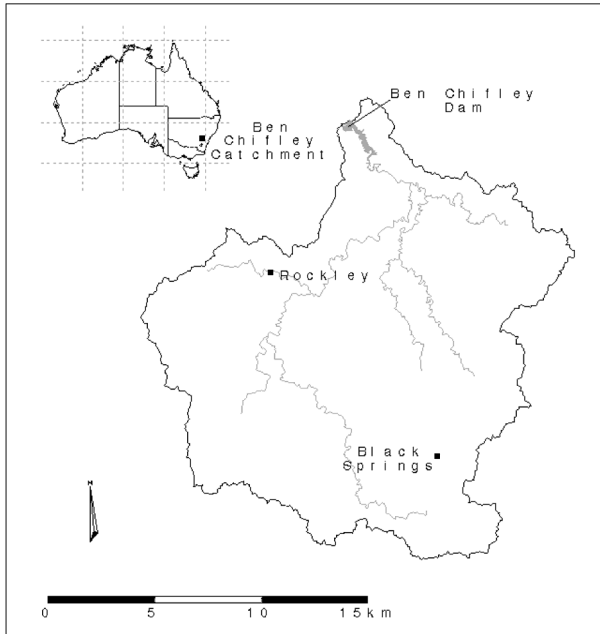
Figure 1. Location of the Ben Chifley Dam Catchment.

Water quality decline is a major environmental degradation concern in the BCDC [Rogers unpublished report]. The decline is manifest in an increased delivery of sediment and nutrient enrichment of streams and water storages. Increased sediment supply through soil erosion can be attributed to the cumulative effects of extensive clearing of native vegetation and inappropriate agricultural and riparian management practices since European settlement in the 1820's [Wasson et al. 1996]. Gully and streambank sources of soil erosion are predominant in the catchment. Gully erosion has been found to contribute 73% of the total sediment yield to the stream system annually [Rogers unpublished report]. Gully erosion has the probable and undesirable secondary influence of accelerating the delivery of diffuse hillslope nutrient sources to the stream network. The mean gully density of the catchment has been calculated as 2.55m/ha (unpublished data). A recent study of the location of gullies in the BCDC has revealed that attributes such as lithology, soil type, slope and elevation are the major factors controlling the formation of gullies [Smith 2002].

3. MODEL FRAMEWORK

The modelling system we are developing to quantify sediment and nutrient delivery to the Ben Chifley Dam needs to satisfy the following criteria:

- adequate simulation of hydrologic and biogeochemical processes under current management conditions;

- identification of catchment areas that currently, or potentially, contribute high loads of nutrients or sediment to streams: so called Critical Source Areas [Heathwaite et al. 2000];

- potential to simulate the impact of current and future land management practices on nutrient and sediment loads reaching surface waters;

- sensitivity to climate variability;

- an ability for on-going comprehensive testing including assessment of the sensitivity of inputs and assumptions; and

- ready incorporation of socio-economic modelling criteria to enable prioritising of ameliorative strategies.

The modelling system has been constrained to a level of complexity not exceeding data availability or process understanding, for example rainfall data constrains the temporal scale of the modelling system to running at a daily interval. Management prescription will extend to the sub-catchment scale, in the order of 10's km^2. Spatial outputs in particular are important in the context of providing management prescription.

The primary catchment drivers that are encapsulated within the modelling system are:

- climate;

- hydrology;

- land use and management practices; and

- riparian management.

The modelling system explicitly considers both particulate and soluble forms of nutrient transport. Consideration of particulate and soluble nutrient transport has been necessary for two reasons: firstly the dominant source of nutrient transport cannot be determined from the available water quality data and secondly the methods developed in the project will be applied more broadly in Australian catchments.

The modelling system is based on a series of linked river reaches. Where possible, river reaches will coincide with the spatial units at which the

drivers of erosion and nutrient delivery are thought to converge. Identification of the appropriate reach structure of the modelling network has already commenced. Allocation of reaches is based on information derived from the application of the following: (i) sediment modelling using a modified SedNet model [Prosser et al. 2001], (ii) modified nitrogen and phosphorus risk indexes [Heathwaite et al. 2000], (iii) stream longitudinal elevation profiles, and (iv) field observation. It is anticipated that individual reaches in the modelling network will be 2-5km in length.

A diagram of the model framework for a single reach is shown in Figure 2.
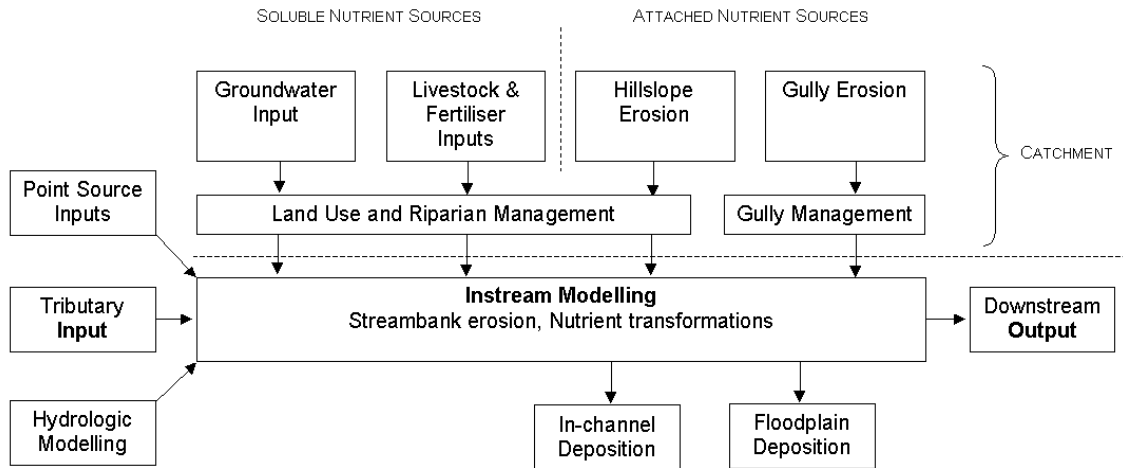
Figure 2. BCDC model framework showing model components for a particular stream reach.

The remainder of this section describes specific components of the model and reports on progress.

3.1 Spatial Data

A comprehensive spatial database has been developed for the catchment within the ARCINFO GIS package. Queries of the database provide the inputs to a number of sub-models of the system, in particular the sediment sub-model and nutrient risk indexes. Table 1 provides a summary of the various data sets contained within the spatial database.

Table 1. BCDC spatial database.

Topographic	Landscape	Cultural
DEM	Geology	Roads
Contour	Soils	Cadastre
Drainage	Land capability	Land use

3.2 Hydrology

Hydrology is an important driver of many of the processes that the BCDC modelling system seeks to simulate. Surface water flows are required to predict sediment and attached nutrient generation and transport in the sediment sub-model. The IHACRES model [Jakeman et al. 1990; Croke et al. this issue] is being used to estimate both surface and sub-surface discharge in the modelling network.
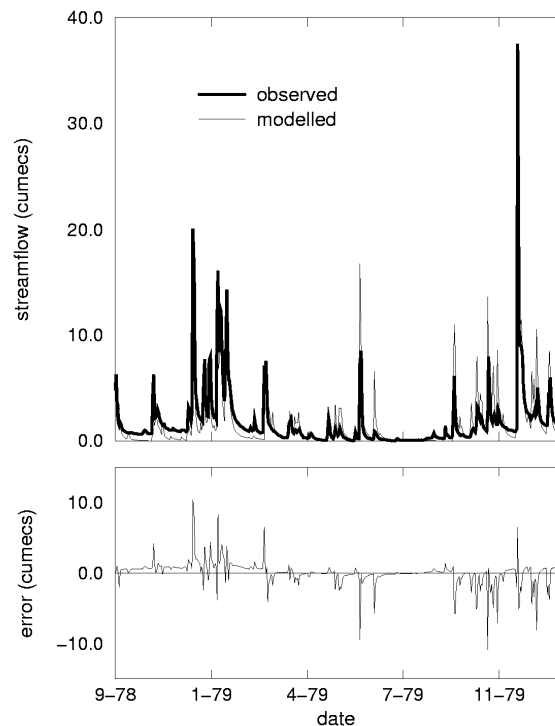
Figure 3. IHACRES modelled and observed streamflow at Campbell's River site 421101.

Within the BCDC, five sites are available to calibrate the IHACRES model. The IHACRES model is being calibrated from historic streamflow and rainfall data at each of these sites. The IHACRES model has been calibrated on the Campbell's River upstream of Ben Chifley Dam (gauge 421101). The calibration was run over a two-year period beginning in August 1978. Figure 3 shows a comparison between modelled and observed data at the Campbell's River site. Model efficiency over the calibration period was 0.726.

Techniques to disaggregate and regionalise IHACRES will be applied at each of the downstream nodes of the modelling system network. The process will allow reconstruction of streamflow from historic climate data throughout the entire stream network of the BCDC. Greater detail on the process of disaggregation may be found in [Newham et al. in prep].

3.3 Sediment Sub-Model

A GIS based model will be used to predict the generation, transport and transformations of sediment and sediment-associated nutrients across the catchment. Processes represented in the SedNet model [Prosser et al. 2001] particularly model implementation based on river links, is being used in this modelling system. The SedNet model constructs sediment budgets sequentially through links of a river network. Three sediment source sub-models are explicitly included in SedNet - hillslope, gully and streambank. Sediment transport and deposition are also modelled with fine and coarse fractions considered separately in the model.

It will be necessary to adapt the SedNet model to the spatial and temporal scales of the BCDC application. The more detailed spatial scale of modelling will enable improved model inputs through catchment specific parameterisation. The overall structure of the steady state SedNet model will required modification to operate dynamically, potentially at daily time intervals. A guide to the prioritisation of data acquisition, parameterisation and changing the structure of the SedNet model has been provided by a separate sensitivity assessment study, see Newham et al. [2001] and Newham et al. [in prep] for further details.

3.4 Nitrogen and Phosphorus Indices

The index approach of [Heathwaite et al. 2000] has been used to assist in identifying the critical sources and transport pathways controlling diffuse hillslope nutrient export in the BCDC. Nitrogen and phosphorus indices are simple tools that have modest data requirements and may be used to prioritise nutrient management at field to catchment scales. The development of nitrogen and phosphorus indices in this project will assist not only in prioritising management, but also help identify the spatial structure of reaches in the modelling network.

Whilst the nitrogen and phosphorus indices were originally developed for North American and European landscapes at the field scale, the processes they represent are generic, and hence with appropriate modification the indices can be applied more broadly. In the BCDC modifications were required due to input data limitations and because of the need to adapt each of the indexes to Australian conditions. In this paper we use the construction of the P index to illustrate modifications and discuss possible improvements.

The P index multiplicatively integrates separate source and transport factors to characterise landscape vulnerability to P loss [Heathwaite et al. 2000]. A summary of the data inputs and associated weighting of data to the P index for the BCDC is found in Table 2. Note that the weighting and factor value ranges remain unchanged in the present application from those used by [Heathwaite et al. 2000].

Table 2. The modified P indexing system used in the BCDC to rate the potential P loss from site characteristics (modified from [Heathwaite et al. 2000]).

Factor		Weight	Value Range	
			Low	High
P Source Potential (Additive)	Soil P	1.0	0 $\rightarrow$	8
	Fertiliser P Rate	0.75	0 $\rightarrow$	8
P Transport Potential (Multiplicative)	Soil Erosion	1.0	0.6 $\rightarrow$	1.0
	Runoff Class	1.0	0.6 $\rightarrow$	1.0
	Contributing Distance	1.0	0.6 $\rightarrow$	1.0
P Index = P Source × P Transport				

A number of significant modifications have been made to the P index for application in the BCDC:

- The scale of implementation of the indices has increased by approximately three orders of magnitude from the applications described by Gburek et al. [1998] and Heathwaite et al. [2000].

- In previous applications [Gburek et al., 1998; Heathwaite et al., 2000] individual fields have been considered as homogenous units. In contrast, only the resolution of the data available for the BCDC limits the indices,

continuous raster data (25m-cell size) has been used where appropriate.

- The predominance of infiltration-excess as opposed to saturation-excess runoff in the BCDC has necessitated modification of the contributing distance weighting. The change modifies the transport potential. The contributing distance weighting is calculated from the distance along the flow pathway in preference to a return period estimate invoked by Heathwaite et al. [2000]. Intuitively, this modification provides an improved representation of the processes of attached nutrient transport.

- Improved connectivity through gully erosion pathways has been incorporated into the indices in the BCDC. Connected gullies have been considered part of the stream network regardless of the size of their contributing area.

Figure 4 shows the phosphorus index for the BCDC. Light tones represent critical source areas for phosphorus management.
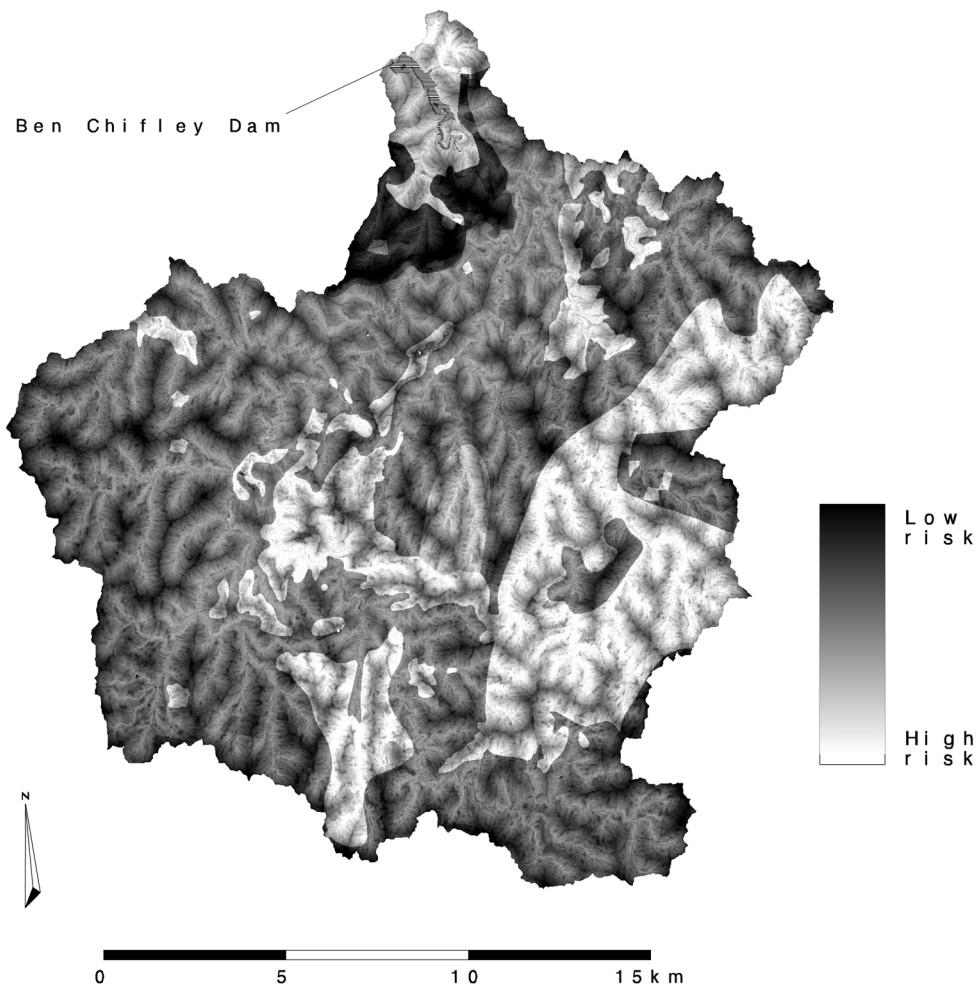
Figure 4. Phosphorus risk index map for the BCDC.

There is much potential to enhance the P index in the BCDC. Data collection activities will be focused on improving the representation of landscape features particularly soil characteristics across the catchment. The intention is to make the index more sensitive to the landscape. The rationale for this is that in contrast to the intensive livestock and agricultural conditions under which the index was developed, the BCDC is an extensive, generally low-input system. Thus inherent landscape features are potentially more important than land management.

3.5 Integrated Socio-Economic Modelling

Social and economic surveying will give sustainability profiles that link biophysical sustainability attributes to the capacity of farmers and impediments to change. The sustainability profiles will be generated through farm surveys using a similar approach to [Watson et al.,

unpublished report]. This will provide information such as the capacity for change in a rural enterprise and the anticipated influence of incentives as well as linking biophysical with socioeconomic characteristics. An output from this component of the project will be the gathering of spatial data on stock numbers and fertiliser application rates for the BCDC. The data will enhance our biophysical modelling capacity including improving the basis of nutrient indices.

4. DISCUSSION

The modelling framework described is innovative because it integrates otherwise separate modelling approaches. More than a biophysical assessment, the modelling framework addresses more broadly social and economic benefits and costs of addressing water quality within the catchment.

Nutrient indices identify potential not actual risk areas.

A suitable platform will be used to incorporate all data and models. Catchment managers, the primary clients for delivery of these tools, will be able to generate and run scenarios to investigate the impact of various management options.

Guidelines on applying the modelling system in other catchments, including costal catchments, will be part of the final output from the project

5. CONCLUSION

The integrated hydrologic, stream sediment and nutrient export modelling system described in this paper will enable the development and evaluation of management scenarios designed to reduce nutrient and sediment delivery to the Ben Chifley Dam. The tools will focus both ameliorative on-ground action at specific sites and hopefully encourage sustainable management practices more broadly in the catchment. The innovation of the modelling system is in integrating otherwise separate modelling approaches.

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