Development of Decision Support Tools to Assess the Sustainability of Coastal Lakes

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EXTENDED ABSTRACT

Coastal lakes in New South Wales provide important ecological, social and economic benefit for much of the state's population. However they are naturally sensitive to catchment inputs, particularly when the lakes are periodically closed to the ocean. Demand on the lakes and their catchment's finite resources through: encroaching urban development; poor agricultural management; the need to protect native flora and fauna; a growing market for seafood; and increasing tourism; is increasing conflict over their use and sustainable management. These issues are intricately linked, so the management of coastal lake systems requires knowledge of the processes and interactions between all key components of the system. This is a complex problem requiring the integration of, often minimal, information, from various disciplines. Few tools exist to assist catchment and lake managers to analyse the whole lake system and make more informed management decisions.

The New South Wales government recognized the threat to the coastal regions and issued a 'Statement of Intent' in 2003, to conduct a Comprehensive Coastal Assessment for the state. Stage one included a sustainability assessment of eight coastal lakes in the state (Cudgen, Myall, Coila, Narrawallee Inlet, Burrill, Wollumboola, Merimbula and Back lakes). The research presented in this paper was conducted to contribute to the Coastal Lake Assessments.

This paper describes the development of a decision support tool to inform of the potential impacts of management decisions on all key components of a coastal lake system. The method used to develop the decision support tool, in short, involved collecting information about potential management decisions, and the key values of the lake, and integrating this into a single, simple tool. A more detailed depiction of the process is presented in Table 1.

The integration was completed using a Bayesian decision network (BDN). This approach was advantageous over other methods because it is suited to the rapid accumulation and integration of existing information sourced from observed data, model simulation and expert opinion, at various scales, from many disciplines. The BDN framework structure also inherently represents uncertainty in the input data but can be readily up-dated when new information becomes available.

Consultation with local stakeholders was an imperative component throughout the whole process, but it played a particularly important role in the development of the BDN framework and in defining the scenarios. The close interaction with future users of the tool meant that the product was more likely to be adopted.

Table 1. Method undertaken for a detailed sustainable assessment of eight coastal lakes in New South Wales, Australia.

Stage	Phase
1	build understanding of constraints, issues and targets for lake and catchment health
2	develop an initial conceptual framework for BDN and potential future scenarios
3	review BDN framework with stakeholders
4	revise initial framework
5	populate BDN links with data
6	incorporate the BDN model into a user friendly software platform
7	review the interface and populated BDN with stakeholders
8	revise interface and populated BDN to reflect stakeholder feedback
9	distribute the sustainability assessment tool to relevant stakeholders with appropriate training in its use.

1. INTRODUCTION

The coastal regions of NSW are appreciated for the social, economic and ecological value they bring to their resident and visiting populations. In recent times there has been an active migration of the human population to coastal areas, as well as an increase in coastal tourism. This creates a greater need for urban development and tourist facilities. At the same time there has been an increased pressure for the conservation of natural ecosystems in the coastal zone. In addition, agricultural production is commonly intensifying in an attempt to remain profitable in the current market. Coastal lakes are naturally sensitive to catchment inputs, but the different use of land, flora, fauna and water within coastal catchments creates pressure and conflict over the management of these limited resources.

In the past coastal management has focused on one or two facets of the system, such as fish species or habitat management (e.g. Alder et al. 2000). However, in order to manage the complex systems of coastal lakes, knowledge of all key processes within the whole catchment is required. In fact, Underwood (2002:487) commented that “Never has there been more need for urgent, integrated and coherent decision-making about coastal environmental issues”. Progress is being made towards a more holistic approach to catchment management (e.g. Bennett and Lawrence 2002, Courtney and White 2000, Alder et al. 2000), but even these can be dominated by one catchment process. For example Ewing et al. (2000:449) describes a hydrological and water quality model with “provision for some basic socioeconomic analysis”.

It is a ‘huge ask’ for catchment managers to have adequate knowledge across all facets of the catchment system to make integrative and informed decisions. Decision support tools are a possible means to integrate such complex systems and array of knowledge, and present it in a simplistic way for them (Ewing et al. 2000). However, the acceptance and therefore the success of such tools depends strongly upon community consultation (Courtney and White 2000, Alder et al. 2000).

This paper presents the method for the development of a decision support tool to assist in Coastal Lake Assessment and Management (CLAM). The approach could be considered another example of Adaptive Environmental Assessment and Management (AEAM), as defined by Ewing et al. (2000). CLAM integrates social, economic and ecological values for the catchment considered. Eight separate tools were developed for eight coastal lake catchments in NSW (Cudgen, Myall, Wollumboola, Narrawallee, Burrill, Coila, Merimbula and Back). The CLAM tool for Merimbula lake is presented and discussed as a case study.

2. BAYESIAN DECISION NETWORK APPROACH

Many approaches exist for integrative modelling. A review by Jakeman et al. (2005) presents various approaches such as expert systems, coupled component models, metamodels, agent-based models and risk assessment approaches. The methods vary in properties such as their ability to account for quantitative verses qualitative data, and their inherent ability to be used in decision-making or to reflect uncertainty. A Bayesian network approach was chosen for this analysis for reasons discussed below.

Bayesian networks conceptualise a system through a series of variables joined by causal links (Pearl 1988). Bayesian Decision Networks (BDN) are structured with decision variables (scenario choices), interim variables (state indicators) and utility variables (outputs or goals).

Catchment planning is unavoidably complex (Ewing et al. 2000) but the BDN approach offers a comparatively simple method of integration because each process does not have to be explicitly represented (Borsuk et al. 2004).

Causal links within the framework represent the relationship between variables using probability distributions. Thus the uncertainty in the relationship between each variable can be explicitly represented (Varis and Kuikka, 1997), allowing the user to make a judgement on the reliability of the model predictions.

BDNs can efficiently incorporate social, economic and ecological values within the modelling framework because the approach lends itself to the easy incorporation of both qualitative and quantitative data (Varis and Kuikka 1997). So when observation data or model simulation is not available, expert and local knowledge can be utilised. As new information becomes available, the BDN can be readily updated (Walters 1986, Borsuk et al. 2004).

Thus the BDN approach provided an efficient method for the integration of social, economic and ecological values within a complex system, utilizing available quantitative and qualitative data and explicitly representing the uncertainty in the model predictions.

3. MODEL AND SOFTWARE DESCRIPTION

The model development process is outlined in Table 1. An initial effort was made to develop a relevant BDN framework but community consultation played an important role throughout the model development process, by providing feedback on the representation of the catchment system and the scenario options.

The probability distributions for each BDN variable (Stage 5, Table 1) were derived through the analysis of observed data, model simulation, a series of general assumptions or expert opinion. Community input was obtained from reports and from direct consultation, and provided expert local knowledge.

Each variable within the BDN framework was calibrated if it was necessary and possible. For variables with a probability distribution determined from on-site observed data, calibration was not necessary. For those variables that utilised model simulation, models were calibrated to local values where the data was available. However, many of the coastal catchments did not have the appropriate information readily available to do this. Local experts reviewed variables that were populated using qualitative data, to ensure that the responses were appropriate for the local conditions.

The revised BDN model framework and the probability distributions were coded into the Integrated Component Modelling System (ICMS) (Stage 6, Table 1). The CLAM interface is a simple computer software package that operates through ICMS. The software consists of eight pages, summarized in Table 2. The supporting text within the software aims to make the tool independent and easy to use. Notable features of the software package include:

- Photographs, map layers of catchment properties and associated text, which provide the user with information to familiarise themselves with the catchment,
- Descriptions of the methods used to generate the probability distributions for each variable, enabling the user to gauge their level of certainty in the model predictions. This make the tool a ‘white-box’, rather than a ‘black-box’ model (Ewing et al. 2000), as the latter is said to have hidden assumptions, and
- Display of output probability distributions for each variable and the function to save and export them, so the user can visually assess the potential impacts of the management scenarios tested.

Table 2. Summary of features available in the CLAM software.

Software Page	Features available
Welcome	Project background, contacts and licensing agreements
Info	Photograph gallery of the catchment, brief list of facts about the catchment
Maps	Series of catchment properties which can be overlaid, such as landuse protected areas, erosion potential etc.
Approach	Brief description of BDN approach and the BDN framework for the catchment
Inputs	Description of how the probability distributions were attained for each variable, including the assumptions and weaknesses for each.
Scenario	Each scenario choice option, plus a map locating various scenarios and a text description of the assumptions used for each scenario.
Utility	Change in the dollar value for the economic variables within the model
Report	A summary of the inputs, scenario choices and the output probability distributions, which can be exported and saved.

Model verification of the BDN is yet to be completed for any of the eight CLAM tools. Given the integrative nature of the model, the most appropriate method for model verification is for various members of the community to use the tool and gauge the performance of the model predictions. This should be completed as part of Stages 7 and 9 (Table 1) upon release of each of the eight tools in October this year.

4. MERIMBULA CASE STUDY

Merimbula Lake is approximately 4.5 sq. km, within a 43.4 sq. km catchment. Half of the catchment is still forested, and only 5% is under urban development, but as with most coastal areas in NSW, development is concentrated around the lake and waterways. The key industries for the catchment are tourism and oyster production, while forestry and cattle grazing also occur.

Within the Lake and its catchment there are wetlands protected under the NSW Governments SEPP 14 protection, as well as koala habitat protection (SEPP 44) and coastal zone protection (SEPP71). In addition it contains an area of South

East Forest National Park and has many important Aboriginal sites around the lakes edge.

Conflicts in management for the Merimbula Lake and its catchment include:

- Encroachment of urban development and tourist facilities upon the lake,
- Maintenance of seagrass beds and fish populations,
- Erosion and sedimentation into the lake
- Lake water quality with regard to oyster production, and
- Management of the airport, which is adjacent to the lake.

4.1. Merimbula BDN framework

Following consulation with the Bega Valley Shire council, Department of Infrastructure, Planning and Natural Resources (DIPNR), Department of Environment and Conservation (National Parks and Wildlife Service) (DEC(NPWS)), the Department of Primary Industries (DPI) (NSW Fisheries and NSW Agriculture) and local oyster producers a BDN framework was developed. Figure 1 shows the framework for Merimbula Lake catchment, illustrating the integrative process of many ecological (water dynamics and quality, and flora, fauna and ecology), social and economic values identified during consultation with the community.

4.2. Populating the BDN

Data analysis, model simulation, general assumptions and expert opinion were used to populate the variables with probability distributions. The method used for each variable is summarised in Table 3. Where possible, the input data and assumptions were reviewed by a local expert to check for consistency and accurate interpretation.

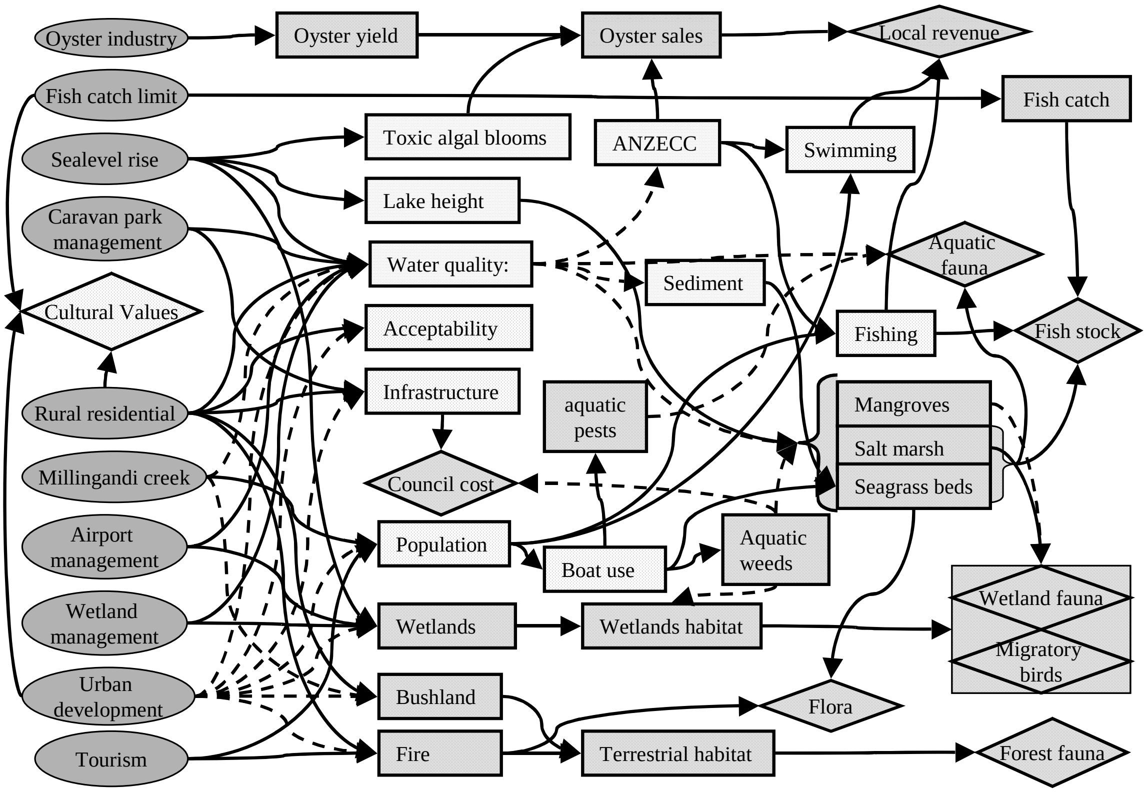

Figure 1. Bayesian Decision Network for the Merimbula Lake CLAM tool.
SHAPES: Ellipse = decision variable, rectangle =state variable, diamond = utility variable.
SHADING: Solid = scenario, spot = water dynamics and quality, vertical dash = social value, chequered= economic value, hashed shading = flora, fauna and ecology.
LINES: lines for links are all equal, the dashed and solid lines are only to assist in interpretation of the plot.
ANZECC = Australian and New Zealand Environmental Conservation Council guidelines, Lake water quality includes nitrogen, phosphorus, suspended sediment, pathogens, salinity and hydrocarbons.

Table 3. Variables and method for determining the probability distribution (PD) for the Merimbula Lake CLAM tool.

Variable	PD method
Acceptability	Data analysis
ANZECC	Data analysis
Aquatic fauna	Expert opinion
Aquatic pests	Expert opinion
Boat use	Expert opinion
Bushland	Data analysis
Council cost	Data analysis
Cultural values	Expert opinion
Fire	Expert opinion
Fish catch	Expert opinion
Fishing	Expert opinion
Fish stock	Expert opinion
Flora	Expert opinion
Forest fauna	Expert opinion
Infrastructure	Assumptions
Lake height	Model simulation
Local revenue	Data analysis
Mangroves	Expert opinion
Migratory birds	Expert opinion
Oyster sales	Data analysis & Assumptions
Oyster yield	Data analysis
Population	Data analysis
Salt marsh	Expert opinion
Seagrass	Expert opinion
Sediment	Assumptions
Swimming	Expert opinion
Terrestrial habitat	Expert opinion
Toxic algal blooms	Expert opinion
Water quality	Model simulation
Wetlands	Data analysis
Wetland habitat	Expert opinion
Wetland fauna	Expert opinion

4.3. Results and discussion

The CLAM tool can be used in many ways to answer various questions. One of the most straightforward being ‘what if?’ type questions. The results presented here seek to illustrate how the CLAM tool can be used when exploring the question of what changes can be made to improve or degrade the Merimbula Lake water quality, and what are the consequences for migratory birds, seagrass cover and local revenue. The results from 4 model runs are shown in Figure 2 with the details of the scenario options given in Table 4. The scenario options were chosen to represent the current conditions (1), high development with current regulations (2), active management for water quality (3), and active management for water quality with urban development with increased regulations (4). Table 5 shows the change in dollar value for local revenue for each scenario.

Table 4. Scenario options chosen for the model simulations 1,2,3 & 4. Current conditions were used where an alternate option is not shown.

Decision variable	Scenario option	1	2	3	4
Rural residential	50m buffer		X		
	150m buffer				X
Urban development	Low density, 150m buffer				X
	Medium density, 50m buffer		X		
Caravan park management	Increased capacity on septic tanks		X		
	Increased capacity, sewered			X	X
Tourism	20% increase in visitors		X		
Airport management	Install artificial wetlands			X	X
Millingandi Creek	50m riparian buffer			X	X
Wetland management	Remove domestic stock			X	X

Table 5. Change in local revenue for each scenario given in Table 4.

Scenario	Change in local revenue ($)
1	3800
2	25364
3	25250
4	32710

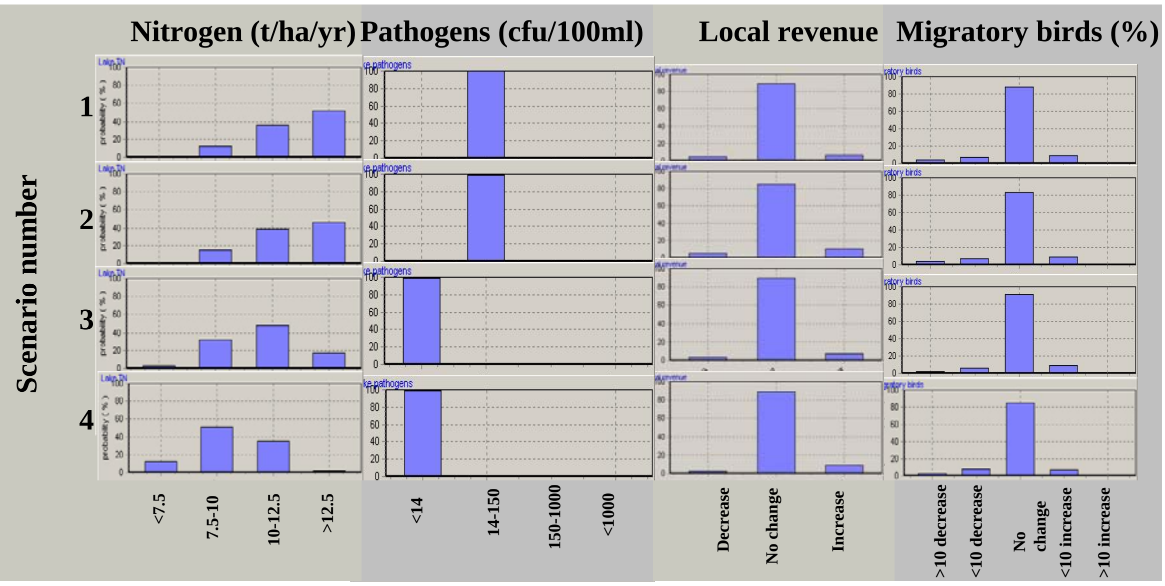

Figure 2. Probability distributions for 4 scenario runs, detailed in Table 4, using the Merimbula Lake CLAM tool.

Figure 2 shows that there is not any significant change in the expected distributions for any of the selected variables between scenarios 1 and 2. That is the current conditions, given by scenario 1, would not significantly change if development occurred within the catchment and tourism increased (Scenario 2). This may be an indication that the impacts of additional development are not substantial in their own right, or it may be that the current pressures on the lake are so high that the additional pressure from the changes of Scenario 2 are comparatively small.

The water quality (nitrogen (TN) and pathogens) shows a marked improvement between scenarios 1 and 2, and 3 and 4. Note that phosphorus and suspended sediment show a similar change as nitrogen, although the results are not shown here. This indicates that there is high potential for improving the water quality of Merimbula Lake through active management methods such as riparian plantings, used in Scenario 3. The large change in the lake pathogens between scenarios 1 and 2, and 3 and 4 is most likely due to changing the sewerage management system of the caravan park from septics (the current system) to sewered on the Merimbula town system. This change in management is currently in progress in the Merimbula catchment, which should see a considerable decrease in the lake's pathogen concentration.

The similarity in the water quality results from Scenarios 3 and 4 also indicates that urban expansion can occur within the catchment with appropriate regulations and additional catchment management, and the likely impact upon the lakes' water quality is minimal and may even improve. Given that the land proposed for urban development is already cleared the planting of vegetation required for the regulation buffers would actually increase the vegetation compared to the current conditions.

The scenarios explored here showed little change in the local revenue, migratory birds, or seagrass cover (not shown due to space), which is most likely due to the scenario options selected for this analysis. Table 5 shows variation in the change in the local revenue, which are possibly too small to see in Figure 2. Scenarios 2 and 3 have a similar change in local revenue (approximately $25,000), but Scenario 3 shows an active improvement in the lake water quality. Thus indicating that management decisions can be made that result in both economic and environmental benefit to the community.

It is important to note that the results presented here are for a select few variables within the Merimbula Lake CLAM tool, and they do not necessarily reflect the likely changes in other model variables. Also, the reader should be reminded that the data used to determine the probability densities vary in method and reliability. Of the variables discussed above, the water quality (nitrogen and pathogens) data was determined through model simulation using inputs values for Merimbula Lake catchment, where available. However, the models used were simple, run at a course scale, and were not spatially explicit to landuse changes (i.e. landuse was accumulated for the catchment as a whole and was not sensitive to the proximity of the landuse change to the lake and streams). Local revenue was also calculated at a course scale because little information was available for the Merimbula Lake Catchment. Thus assumptions were made on the proportion of the Bega Valley Shire revenue raised within the Merimbula Lake catchment. The direction of change in revenue is believed to be correct, but the absolute values need to be reviewed. More certain values can be added following the completion of a complementary project on the economy generated from Merimbula Lake by the Department of Environment and Conservation. Information on migratory birds and change in seagrass cover are currently only based upon general assumptions derived from the literature. The certainty of the results will be increased following a review by experts, which is currently underway.

Thus the CLAM model for Merimbula is yet to be verified by members of the community and other experts, so the results presented here are only preliminary.

5. SUMMARY AND CONCLUSIONS

The sustainable management of the coastal lakes in NSW is under pressure from increasing urban development and tourism, intensification of agriculture, and the growing importance for the conservation of flora and fauna. An integrative approach is necessary to be able to manage for all these often conflicting interests.

This paper presented a tool, called the CLAM (Coastal Lakes Assessment and Management) tool, which uses a Bayesian Decision Network to identify the likely impacts of management decision on social, economic and ecological variables within a catchment. Community consultation was an imperative component of the model development, and will also be pursued for model verification in the future.

A CLAM tool for the Merimbula Lake was presented as a case study. The brief analysis of the model results given showed that active management of the Merimbula Lake catchment is likely to significantly improve the lake water quality. It also showed that urban development can proceed within the catchment without negatively impacting upon the lake water quality, if appropriate regulations are imposed and catchment management occurs. Various management options were shown to increase the local revenue, but not all of them did so while improving the lake's water quality.

The CLAM tool is believed to be a useful tool and a dynamic approach, to assist catchment managers in making decisions. Ewing et al. (2000:456) comments that such tools are only to assist in decision making as they do "not substitute for the complex processes of judgement and the many political realities of planning". This is true, but at the same time tools such as CLAM, can show the impact of management decisions on social, economic and ecological values important to a community, and thus stand to highlight decisions made primarily for personal gain by those in charge, as has been the case in the past.

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7. REFERENCES

Alder, J., R. Hilliard and G. Pobar (2000), Integrated marine planning for Cocos (keeling), an isolated Australian Atoll (Indian Ocean), *Coastal Management*, 28:109-117.

Bennett, J. and P. Lawrence (2002), Adaptive management framework for catchment and coastal management decision making, Coastal CRC conference, 2002, 24-27 sourced http://www.coastal.crc.org.au/coast2coast/proceedings/Theme2/Adaptive-management-framework.pdf

Borsuk, M.E., Stow, C.A. and Reckhow, K.H. (2004) A Bayesian network of eutrophication models for synthesis prediction, and uncertainty analysis. *Ecological Modelling*, 173:219-239.

Courtney, C.A. and A.T. White (2000), Integrated coastal management in the Philipines: Testing New Paradigms, *Coastal Management*, 28:39-53.

Ewing, S.A., R.B. Grayson and R.M. Argent (2000), Science, citizens, and catchments: Decision support for catchment planning in Australia, *Society and Natural Resources*, 13:443-459.

Underwood. T (2002), Our coastal environments are on the rocks: Research needs for sustainable coastal management, Coastal CRC conference, 2002, 487-490 sourced http://www.coastal.crc.org.au/coast2coast2002/proceedings/Plenary/Our-coastal-environments-are-on-the-rocks.pdf

Varis, O. (1995) Belief networks for modelling and assessment of environmental change. *Environmetrics*, 6, pp. 439-444.

Walters, C.J. (1986) *Adaptive management of renewable resources*. MacMillan, New York.