Cobaki Broadwater Sustainability Assessment Report

December 2006

Rebecca Letcher, Charles Hewitt,Wendy Merritt,
Jenifer Ticehurst

CLIENT REPORT 2006/ 09

Integrated Catchment Assessment and Management (iCAM) Centre
THE AUSTRALIAN NATIONAL UNIVERSITY

PROJECT: Coastal Lake Assessment and Management (CLAM) – Phase 1

CLIENT: Northern Rivers Catchment Management Authority

☐ RESTRICTED DISTRIBUTION ☒ PUBLIC DISTRIBUTION

Letcher, R. Hewitt, C. Merritt, W. and Ticehurst, J. (2006). Cobaki Broadwater Sustainability Assessment Report, December 2006, iCAM Client Report 2006/09, The Australian National University, Canberra, ACT.

DIRECTOR: Professor Tony Jakeman

Building 48a, Linneaus Way
The Australian National University ACT 0200
Phone (02) 6125 4742 Fax (02) 6125 0757
Email: tony.jakeman@anu.edu.au

ALL QUERIES CAN BE ADDRESSED TO:
Dr Rebecca Letcher
Building 48a, Linneaus Way
The Australian National University ACT 0200)
Phone: 0438 230 246
Email: rebecca.letcher@anu.edu.au

CONTENTS

EXECUTIVE SUMMARY

This Sustainability Assessment report is based on results from the Coastal Lake Assessment and Management (CLAM) tool for Cobaki Broadwater. This tool was developed as part of the Northern Rivers Catchment Management Authority (CMA) funded project entitled 'Ensuring sustainable development in coastal lake catchments of NSW Northern Rivers (CLAM project)'.

The report summarises the quality of data in the Cobaki Broadwater CLAM for each node and also provides an assessment of key data gaps identified by Charles Hewitt in putting the Cobaki CLAM together. These gaps are:

- Extent of riparian vegetation "coverage". Riparian planting is a common program among resource managers, and many will want to assess the associated cost-benefit. Without information on existing "coverage" this is very hard, and also makes export rates hard to calculate.
- Pollutant capture rates of riparian planting, WSUD elements, stormwater enforcement, education etc., particularly for pathogens.
- Number of septics on a catchment basis. These had to be estimated from aerial photographs.

Three groups of scenario combinations were analysed:

- Riparian management;
- Sea level rise; and,
- Community education.

These are a small number of the total scenario combinations available in the CLAM but provide a useful insight in themselves into the management of the lake. Key conclusions from this analysis are summarised below.

Riparian management

Riparian management is seen to have fairly mixed outcomes on water quality and ecology. Potential improvements in TN, TP and TSS were not realised in the results but riparian management was shown to lead to very substantial increases in pathogen levels as native fauna increased in these areas. This is also a positive for the catchment, improving outcomes for terrestrial fauna. A small increase in seagrasses and saltmarsh was also predicted but only under the largest amount of riparian revegetation. Care should be taken in using these results given the data quality underlying these results however they provide an interesting illustration of possible unforeseen negative consequences of management actions. Better information should be obtained to ensure these results accurately reflect the likely impacts of these management options. If these results are accurate then they reflect the need to consider trade-offs increased costs to council and developers and increased pathogen levels as well as associated reductions in recreational amenity against increases in terrestrial fauna and very small improvements in other water quality and aquatic ecology outcomes.

Sea level rise

Sea level rise is shown to be associated with two primary impacts: an increase in lake water levels; and, a decrease in the time taken to flush the lake. Flushing was seen to be impacted only at 2050 or higher water levels (not 2030) while lake level was impacted for all sea level rise options. These impacts then have a range of follow-on impacts on the system. Increasing water levels generally increases flooding and associated costs while reducing the area available for seagrass habitat given reduced light levels. Decreased flushing times are associated with a reduction in pollutants such as TN, TP and TSS and consequently can be expected to reduce seagrasses, algae and phytoplankton. Sea level rise also reduces the extent of mangroves. The results for aquatic fauna showed the presence of threshold effects where one level of rise is associated with negative effects while others show no impact or even positive outcomes. While these results are based on poor quality data and so should be

used cautiously, this result illustrates the difficulties associated with estimating the nature of impacts on values that depend on a complex array of relationships with the environment.

Community education

Community education is associated with small improvements in water quality in terms of both nitrogen and phosphorus. These improvements are likely to reduce algae and phytoplankton which in turn has positive outcomes for seagrasses and saltmarsh, although these impacts can be expected to be quite small. Community education also has direct impacts on weeds and domestic pet management which in turn have benefits for migratory birds and terrestrial fauna. It was shown to be likely that the greatest benefits of education programs will be on the terrestrial environment through changes in pet and weed management rather than on the aquatic environment through changes in water quality.

The results for community education and riparian management both indicate that while these programs can bring about significant improvements in outcomes for terrestrial fauna, water quality improvements can be expected to be quite subtle. In the case of riparian management this action can be expected to induce declining water quality when considering pathogen levels. When designing such programs it is important to be aware of the possibility of negative consequences for water quality as well as the likelihood that benefits may be best observed in the terrestrial environment. When assessing such programs some monitoring of terrestrial effects as well as those on water quality would be advisable to allow these benefits to be captured. Given the small nature of changes in water quality it is also unlikely that these types of programs could be used to offset the water quality effects of actions such as urban development unless these actions were expected to have very small impacts on water quality.

1 Introduction

This Sustainability Assessment report is based on results from the Coastal Lake Assessment and Management (CLAM) tool for Cobaki Broadwater. This tool was developed as part of the Northern Rivers Catchment Management Authority (CMA) funded project entitled 'Ensuring sustainable development in coastal lake catchments of NSW Northern Rivers (CLAM project)'. Scenarios presented in this report were identified as an important primary focus during workshops held with Council staff and other stakeholders in November 2006. These scenarios represent a relatively small subset of the complete range of options available in the CLAM tool and are intended to:

- document the quality of data used in the Cobaki CLAM and key data gaps which should be a priority for data collection
- provide a useful analysis of options of first concern to Council and other key stakeholders which can be incorporated in decision making and other planning activities on these issues; and,
- illustrate the way in which the CLAM tool can be used to show the trade-offs involved in managing the lake system.

This report is not a management plan and cannot take the place of activities associated with the development of such a plan. In particular this report did not include scope for comprehensive community consultation. It could however be used to inform such a planning process. If this were to occur, results in this report should be critically evaluated and open to criticism from members of the public. This needs to occur within the context of the supporting documentation provided in the input pages of the CLAM tool. These pages provide comprehensive documentation of the assumptions underlying data used to derive the results in this report. This information is provided to allow users to assess for themselves the varying quality of data sources underlying the CLAM tool and its relevance to the decisions being made.

1.1 What is CLAM?

The Coastal Lake Assessment and Management (CLAM) tool was developed to allow stakeholders to assess the social, economic, environmental and ecological trade-offs associated with development, remediation and use options for coastal lakes and estuaries. A population shift towards the coastal fringe in NSW has seen substantial pressures being placed on these coastal systems. Catchment areas are subject to a variety of activities including urban developments, forestry and agricultural activities, recreation and tourism and fishing and aquacultural activities. Remediation of impacts through better controls on developments, replanting of riparian areas and remediation of fringing wetlands, as well as controls on activities directly affecting estuaries such as boating, fishing and recreation are also frequently being considered by State and Local authorities. The CLAM has been developed to show the multitude of impacts arising from such pressures and potential remediation measures. It is most appropriate for strategic planning purposes such as the development of estuary management plans or in other planning activities where a high level of community participation is desirable and an open and transparent modelling tool, which provides full detail of assumptions made and data used in its population, can be of assistance.

The CLAM approach is based on the concept of Bayesian networks but provides additional decision support through tailored interfaces and in-model documentation of model assumptions and design process. More details on the CLAM model can be found in Merritt *et al.* (2006a, 2006b) and Ticehurst *et al.* (2005, 2006).

There are five main benefits which the CLAM is able to capture for strategic decision making and management activities:

- To document in a transparent way data and assumptions available to be used in making a decision;
- To allow such data and assumptions to be applied repeatedly over many (often 100,000's) iterations in a consistent manner to improve the consistency and rigour of decision making;
- To provide a sound prioritisation of key data and information gaps in the management of a lake system through open documentation of data used in the CLAM system and analysis of the implications of the uncertainty of this data for decision making;
- To play an education role, providing a tool for people to focus on learning more about the interactions between human actions and social, environmental and economic outcomes in the system;
- To provide a focus for negotiations and discussions about preferred management actions. The CLAM approach encourages people to verbalise and document why they agree or disagree with model results. This type of discourse can form a key component of any negotiation about preferred options and the nature of impacts on the system. Improved understanding and knowledge developed through such discussions and studies which come out of them can be used to update the knowledge in the CLAM system.

1.2 How should the CLAM tool and results in this Sustainability Assessment Report be used?

The CLAM tool and the results provided in this Sustainability Assessment report should be used carefully. In particular all results from the CLAM should be critically evaluated for their appropriateness before being used to make decisions. All assumptions used in populating the CLAM and any review of the data that has been undertaken are documented in the input pages found with the CLAM model. This information should be very carefully considered when using results to make any type of decision or recommendation. In particular, users should consider:

- Does the CLAM consider the specific scenarios you are interested in?
- Do the impacts look reasonable? If not, why not? If yes, why?
- Do you trust the data used to populate the model? Why/why not?
- Is there other better data available that could be used in the model or used to review/validate the results?

The CLAM has a strong potential to be used in negotiations between catchment stakeholders on management actions. It should also be useful in an educational and capacity building role.

2 COBAKI CLAM

2.1 Conceptual framework

The Cobaki Broadwater CLAM model is underpinned by the conceptual framework shown in Figure 1. This diagram shows the assumed dependencies between scenarios or actions and state variables. This demonstrates, for example, the way in which ecological outcomes, such as seagrass, are dependent on water quality parameters such as total suspended sediment or sedimentation, which in turn depend on actions such as implementing new developments or stormwater management. A description of all nodes in this framework is provided in Appendix 1.

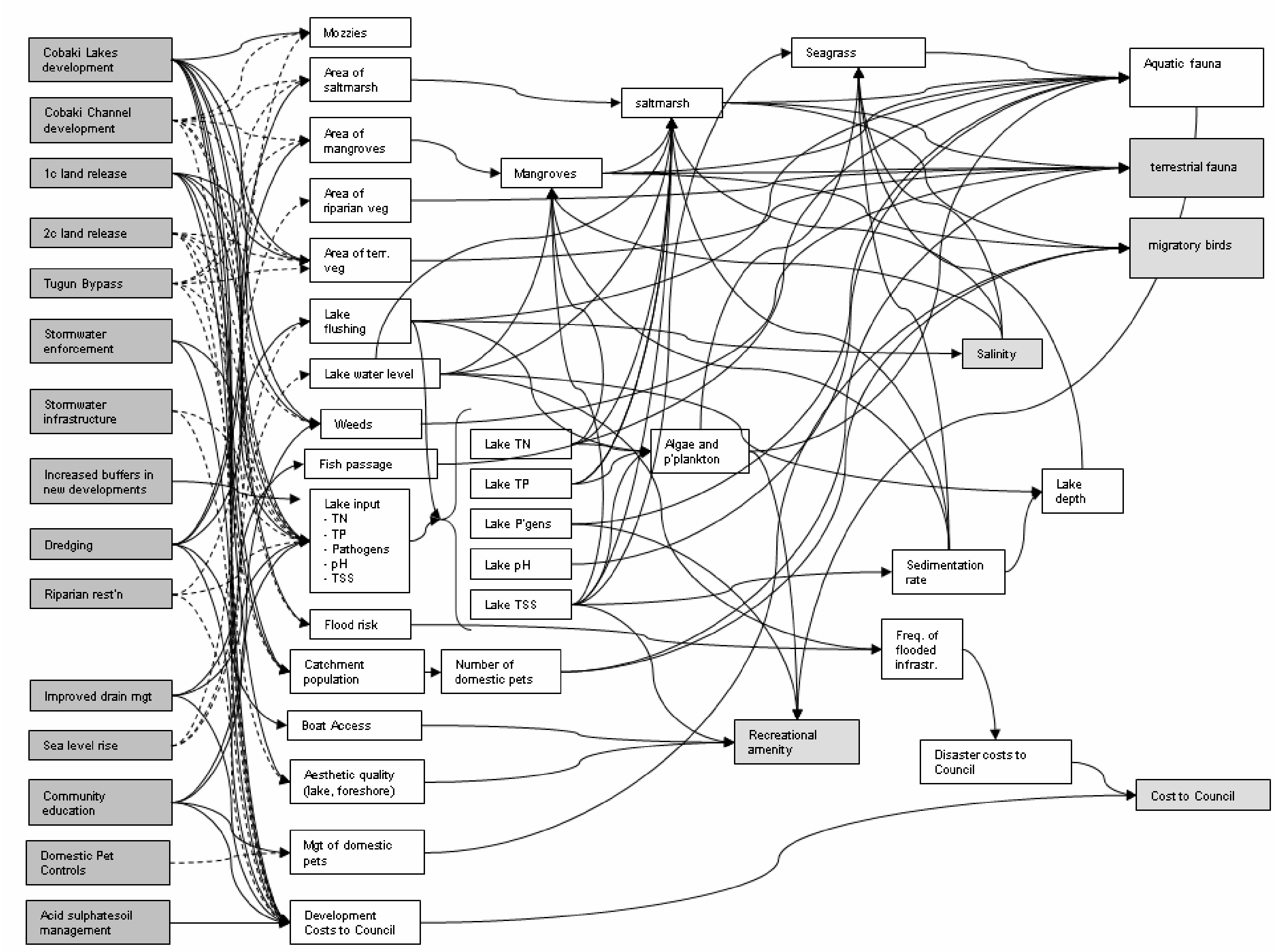

Figure 1. Cobaki Broadwater conceptual framework

2.2 An assessment of data quality

The CLAM model relies upon a set of conditional probabilities to define the relationship between variables. This means that for every arrow in Figure 1 a conditional probability table must be defined which estimates the nature of the relationship. The data used to derive these conditional probability tables comes from variety of sources including literature assumptions, calibrated and uncalibrated models, expert and local knowledge and observed data. For such a broad system a variety of data qualities is to be expected. This section provides quality assessment of data quality for each node (ie. each box in Figure 1). A statement of priority data collection needs for Cobaki lagoon is then given. This statement was provided by Charles Hewitt who was put together the data for the Cobaki CLAM.

Table 1 provides a qualitative assessment of data quality for each node in the Cobaki CLAM.

Table 1. Data quality in the Cobaki CLAM

Node	Quality of Data	Reason	Suggested improvements
Foreshore aesthetics	Poor	Based on assumptions and iCAM combination model tool	Expert review and data input from local information on perceptions of foreshore aesthetics. Further community consultation.
Algae and Phytoplanton	Poor	Based on assumptions and iCAM combination model	Expert review and increased knowledge of the interactions between nutrients and algae or phytoplankton response in Cobaki or similar systems.
Aquatic fauna	Poor	Based on assumptions and iCAM combination model	Expert review and increased knowledge of the aquatic fauna ecology in Cobaki or similar systems.
Boat access	Poor	Based on assumptions and iCAM combination model	Expert and local review and increased knowledge of impact of options on boating access.
Cost to Council	Poor	Based on assumptions and iCAM combination model	Expert and local review and review of current council cost structures and relative impacts.
Development costs	Poor	Based on assumptions and iCAM combination model	Expert and local review and review of current development cost structures and relative impacts.
Direct mangrove impacts	Poor	Based on assumptions and iCAM combination model	Expert and local review. Would also be assisted by GIS or photo interpretation to map mangrove areas (if not already available) and to provide some quantitative estimate of impacts.
Direct riparian vegetation impacts	Poor	Based on assumptions and iCAM combination model	Expert and local review. Would also be assisted by GIS or photo interpretation to map riparian vegetation (if not already available) and to provide some quantitative estimate of impacts.

Direct Saltmarsh impacts	Poor	Based on assumptions and iCAM combination model. Conflicting information as to the occurrence of saltmarsh communities and possible impacts.	Expert and local review. Would also be assisted by GIS, photo interpretation and ground-truthing to map areas of current saltmarsh (if not already available), determine suitability of artificial islands for saltmarsh and to provide some quantitative estimate of impacts.
Direct terrestrial vegetation impacts	Average	Based on GIS data and iCAM combination model tool	Expert and local review. Improved assessment of total area the 80m buffer option (Buffer Extent) would be applied to.
Disaster costs	Poor	Based on assumptions and iCAM combination model	Expert and local review and review of costs associated with flooding in Cobaki or similar areas.
Domestic pets	Average	Based on assumptions and iCAM combination model with generic data input	Expert and local review and review/data on pet ownership trends in Cobaki
Domestic pet management	Poor	Based on assumptions and iCAM combination model	Expert and local review and review/data on pet ownership and management trends in Cobaki
Fish passage	Poor	Based on unsupported assumptions.	Expert and local review and review of fish species and movements in Cobaki or similar systems.
Flood risk	Poor	Based on assumptions and iCAM combination model	Expert and local review and flood study or similar
Frequency of flooded infrastructure	Poor	Based on assumptions and iCAM combination model	Expert and local review and flood study or similar
Lake depth	Poor	Based on assumptions and iCAM combination model	Expert and local review, Application of flood study or similar and bathymetry of Cobaki Broadwater if available
Lake flushing	Average	Based on a simple uncalibrated model. Local data were used to run this model.	Expert and local review. Could be improved with local hydrodynamic modelling.
Mangroves	Poor	Based on assumptions and iCAM combination model	Expert and local review.
Migratory birds	Poor	Based on assumptions and iCAM combination model	Expert and local review. More information on habitat use by migratory birds in Cobaki.
Mosquitoes	Poor	Based on assumptions and iCAM combination model	Expert and local review. More information on mosquito ecology relevant to Cobaki scenarios.
Pathogen input	Average	Based on simple uncalibrated model derived from other situations. Model run with local data	Expert review and more comprehensive local data collection, use of local data for calibration and implementation of the more comprehensive model.

Lake pathogen	Average	Based on model with some local data but primarily uncalibrated	Expert review and more comprehensive local data collection, use of local data for calibration. More detailed modelling of flushing impacts on pathogens and monitoring of levels in the lagoon could also be undertaken.
pH input	Poor	Based on assumptions and iCAM combination model	Expert and local review. Local data collection for calibration or baseline data.
Lake pH	Poor	Based on assumptions and iCAM combination model	Expert and local review. Local data collection for calibration or baseline data.
Population	Average	Based on assumptions and iCAM combination model with some quantification.	Expert and local review. Use of ABS census data or other data on local population would strengthen assumptions (assumptions not documented)
Recreational Amenity	Poor	Based on assumptions and iCAM combination model	Expert and local review. Local data on recreational activities and behaviour to allow better representation of impacts of different node inputs
Lake salinity	Average	Based on a simple uncalibrated model. Local data were used to run this model.	Expert and local review. Could be improved with local hydrodynamic modelling.
Saltmarsh	Poor	Based on assumptions and iCAM combination model	Expert and local review. Would also be assisted by GIS, photo interpretation and ground-truthing to map areas of current saltmarsh (if not already available), changes in saltmarsh community and better understanding of saltmarsh ecology to provide some quantitative estimate of impacts.
Seagrass	Poor	Based on assumptions and iCAM combination model	Expert and local review. Would also be assisted by GIS, photo interpretation and ground-truthing to map areas of current seagrass (if not already available), changes in seagrass extent and better understanding of seagrass ecology to provide some quantitative estimate of impacts.
Sedimentation rate	Poor	Based on assumptions and iCAM combination model	Expert and local review. It would be much more appropriate to link Lake TSS to Sedimentation Rate via a direct relationship based on wet bulk density of sediment, area of the lake, and an assumption of the proportion captured by the lake.

Terrestrial fauna	Poor	Based on assumptions and iCAM combination model	Expert and local review. Data/information on local terrestrial fauna biodiversity and ecology.
TN input	Average	Based on an uncalibrated model with some local data	Expert and local review. Local data collection to provide calibration/validation data sets.
Lake TN	Average	Based on an uncalibrated model (with some local data)	Expert review and more comprehensive local data collection, use of local data for calibration. More detailed modelling of flushing impacts on TN and monitoring of levels in the lagoon could also be undertaken.
TP input	Average	Based on an uncalibrated model with some local data	Expert and local review. Local data collection to provide calibration/validation data sets..
Lake TP	Average	Based on an uncalibrated model (with some local data)	Expert review and more comprehensive local data collection, use of local data for calibration. More detailed modelling of flushing impacts on TP and monitoring of levels in the lagoon could also be undertaken.
TSS input	Average	Based on an uncalibrated model with some local data	Expert and local review. Local data collection to provide calibration/validation data sets.. Information on riparian areas to inform model.
Lake TSS	Average	Based on an uncalibrated model (some local data)	Expert review and more comprehensive local data collection, use of local data for calibration. More detailed modelling of flushing impacts on TSS and monitoring of levels in the lagoon could also be undertaken.
Lake water level	Average	Based on simple model with limited local data	Expert and local review. Local hydrodynamic model.
Weeds	Poor	Based on assumptions and iCAM combination model	Expert and local review. Data/information on current status and ecology of weeds in the catchment.

Priority data collection areas identified by Charles Hewitt are:

- Extent of riparian vegetation "coverage". Riparian planting is a common program among resource managers, and many will want to assess the associated cost-benefit. Without information on existing "coverage" this is very hard, and also makes export rates hard to calculate.
- Pollutant capture rates of riparian planting, WSUD elements, stormwater enforcement, education etc., particularly for pathogens.
- Number of septics on a catchment basis. These had to be estimated from aerial photographs.

3 SCENARIOS

In order to develop this Sustainability Assessment analysis a relatively small subgroup of scenarios were selected from the 1,228,800 available in the Cobaki CLAM. In was decided to focus on the following scenarios:

- Riparian Management;
- Sea Level Rise; and,
- Community Education.

These sets of scenarios are considered in isolation to each other. Impacts focused on depend on the likely consequence of the scenario options. The descriptions for these scenarios taken from the CLAM tool are given below. Other scenarios available in the CLAM tool are described in Appendix 2.

3.1 Riparian Management

Tweed Shire Council works with land holders throughout the total catchment of Cobaki Broadwater (i.e. the combined catchments of Piggabeen Creek, Cobaki Creek and Cobaki Broadwater) to encourage riparian planting. Such works aim to reduce nutrient export from upslope areas, reduce streambank erosion and limit cattle access to creeks (thereby limiting pathogen export).

It was assumed that all planting would occur directly downslope of the three landuse classifications associated with agriculture, namely improved pasture, unimproved pasture and cropping. A representative of Tweed Shire Council has indicated that riparian 'coverage' of these landuses is low, however no quantitative data on the proportional 'coverage' of these landuse classifications throughout the total catchment is available. An assumption of 2.5% coverage of each landuse classification was made.

The scenario options modeled are
1. no planting
2. 5 km of planting
3. 10 km of planting
4. 20 km of planting

In order to translate these lengths of riparian planting works into additional percentage coverage of a certain landuse, an estimate of the total stream length through the catchment was made (105 km). The proportion of total stream length represented by the length associated with each planting option was then assigned to each of the three landuse classifications via a weighted average of existing landuse area.

3.2 Sea Level Rise

The sea level is predicted to rise in the future due to climate change. The climate change scenarios were estimated from Whetton and Holper (2001) and reviewed by Dr Kevin Walsh, CSIRO atmospheric Research (pers. comm. September 2004).

The options are to predict the increase in sea level by the year 2030, 2050 and 2100. The predicted sea level rise (cm) from values in the year 2004 used here were:

Rate of sea level rise	2030	2050	2100
Low	2	3.6	7.6
Medium	11	19.8	41.8
High	20	36	76

3.3 Community Education

Community education can have a positive effect on the export rates of TN, TP, TSS and pathogens via improved behaviour associated with garden management, hosing, on-site sewage management, domestic pet management etc. No quantitative data was used to inform the effect of this scenario, however, the following assumptions were made on the decreases in export rates that could be expected from a community education program.

- TN – 10% reduction
- TP – 10% reduction
- TSS – 10% reduction
- Pathogens – 20% reduction

4 RESULTS FROM SCENARIO RUNS

4.1 Riparian Management

Four alternative riparian management options were considered, including a no change option. Active management considered the consequences of revegetating 5, 10 and 20 kilometres of riparian areas. Overall this scenario had no impact on 27 nodes: Water_Lvl; Algae_&_Phytoplankton; TN_input; Disaster_Costs; TP_input; Population; Direct_Terrestrial_Vegetation_Impacts; Mozzies; Aesthetics; Domestic_Pets; Aquatic_fauna; Salinity; Direct_Saltmarsh_Impacts; Domestic_Pets_Mgt; Weeds; Direct_Mangrove_Impacts; pH_input; Flood_Risk; Freq_infra_flood; Boat_access; Fish_Passage; Lake_Flushing; TSS_input; TN_lake; TP_lake; TSS_lake; Mangroves; and, pH_lake. Impacts on other nodes are summarised in Table 2.

Table 2. Summary of impacts of Riparian Management

Node	5 km	10 km	20 km
Rec_Amenity	No impact	Very small decrease	Very small decrease
Pathogen_input	No impact	Moderate increase	Moderate increase
Lake_Depth	No impact	No impact	Moderate increase
Sedimentation_rate	No impact	No impact	Moderate decrease
Saltmarsh	No impact	No impact	Very small increase
Dev_Costs	No impact	Moderate increase	Moderate increase
Seagrass	No impact	No impact	Small increase
cost_to_council	No impact	Moderate increase	Moderate increase
Direct_Riparian_Vegetation_Impacts	Moderate increase	Moderate increase	Large increase
pathogens_lake	No impact	Moderate increase	Moderate increase
Terrestrial_Fauna	Very small increase	Very small increase	Small increase
Migratory_Birds	No impact	No impact	Very small increase

These results show that riparian management is expected to have very little impact on any water quality parameter with the exception of pathogens which is expected to increase under the two largest revegetation options. This is likely to be because of the increased native fauna associated with these riparian areas. Riparian management also reduces sedimentation of the lake but only noticeably for the largest revegetation option. Ecological consequences are a small increase in seagrass and saltmarshes due to the changed sedimentation. The largest riparian revegation option (20 km) is also expected to lead to a small increase in terrestrial fauna and a very small increase in migratory birds.

Figure 2 shows the impacts of riparian management on lake pathogens in more detail. This shows that there is a substantial shift in pathogen levels, which corresponds to levels being in the "No aquaculture" range (14-150 cfu/100ml) all of the time, up from less than 20% of the time. This result is attributable to the increased numbers of water birds and native fauna associated with these options. Model assumptions essentially infer that the pathogen input from these sources is greater than would have been the case from sheep and cattle on an equivalent area of agricultural land.

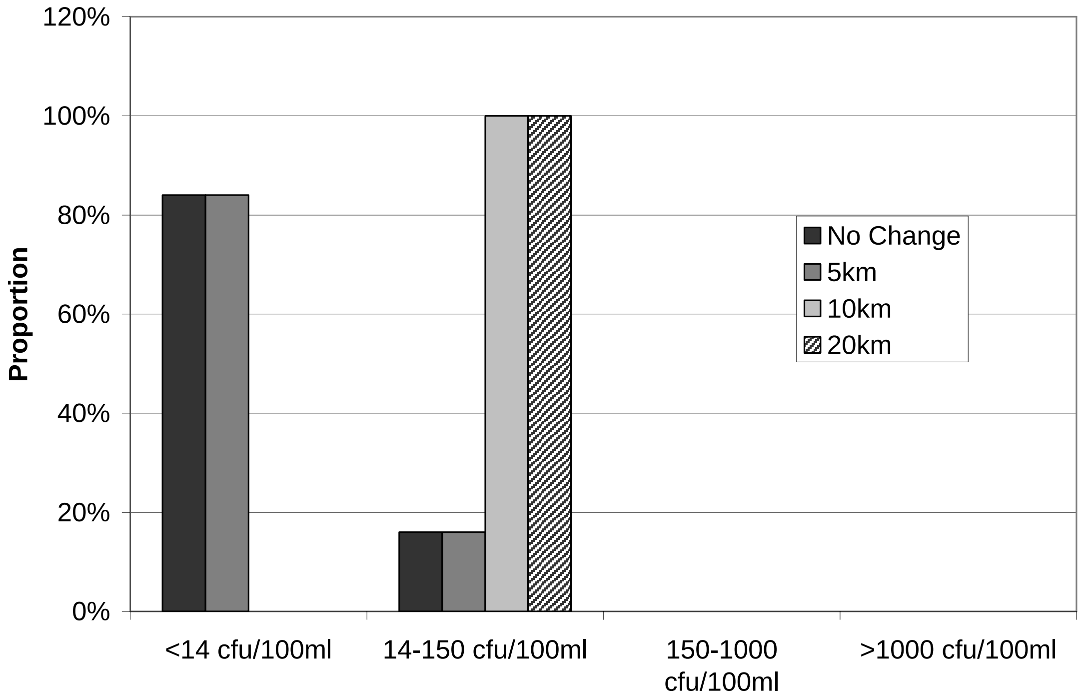

Figure 2. Impact of Riparian Management on Lake pathogens

Impacts of riparian management on seagrasses are shown in more detail in Figure 3. This figure shows that no impact is experienced for most riparian management scenarios. Only when riparian management reaches 20 km is an impact seen. The most likely outcome in all cases is 'no change' however under the 20 km option the probability of this outcome is reduced. Under this option the chance of a small increase in improves and a small probability exists that there will be a large increase in seagrasses.

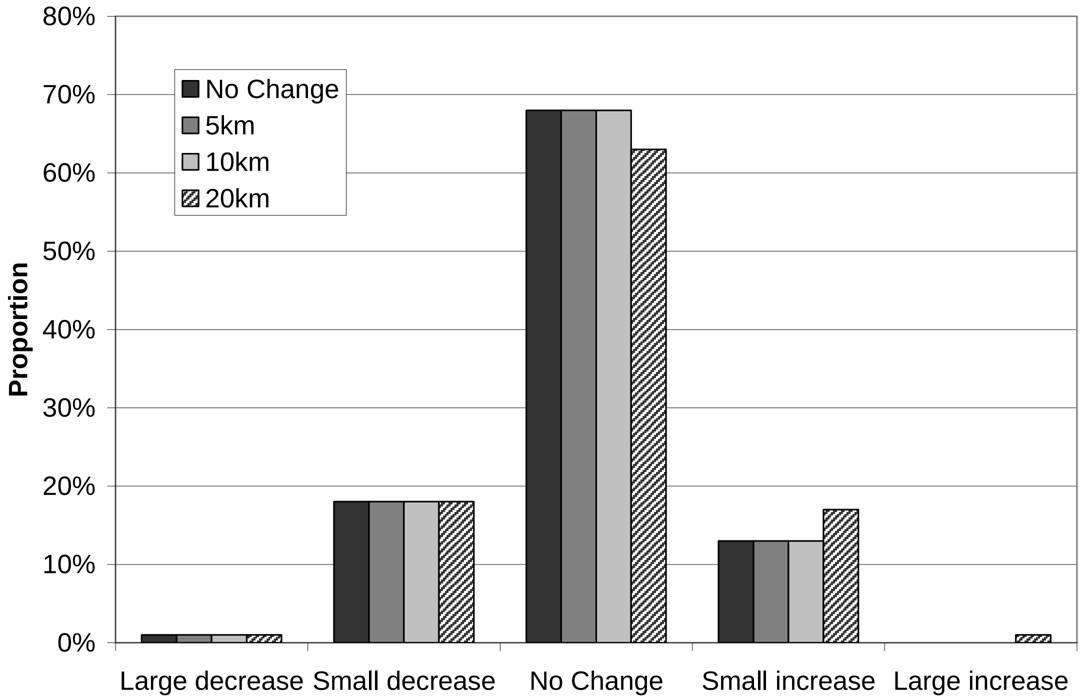

Figure 3. Impact of Riparian Management on seagrass

While seagrasses are not impacted until the largest riparian management option is implemented, outcomes for terrestrial fauna are improved for all levels of riparian management (Figure 4). The most likely outcome under all options is 'no change' however there is a substantial chance (>30%) of a small decrease under the base case. Riparian management reduces the chance of a small decrease under all options and improves the chance of 'no change'. The largest riparian management option has the greatest impact on these values and also leads to a smaller chance of a large decrease and a larger chance of a small increase. Thus while all levels of riparian management have some effect on terrestrial fauna, the larger this investment the greater the impact.

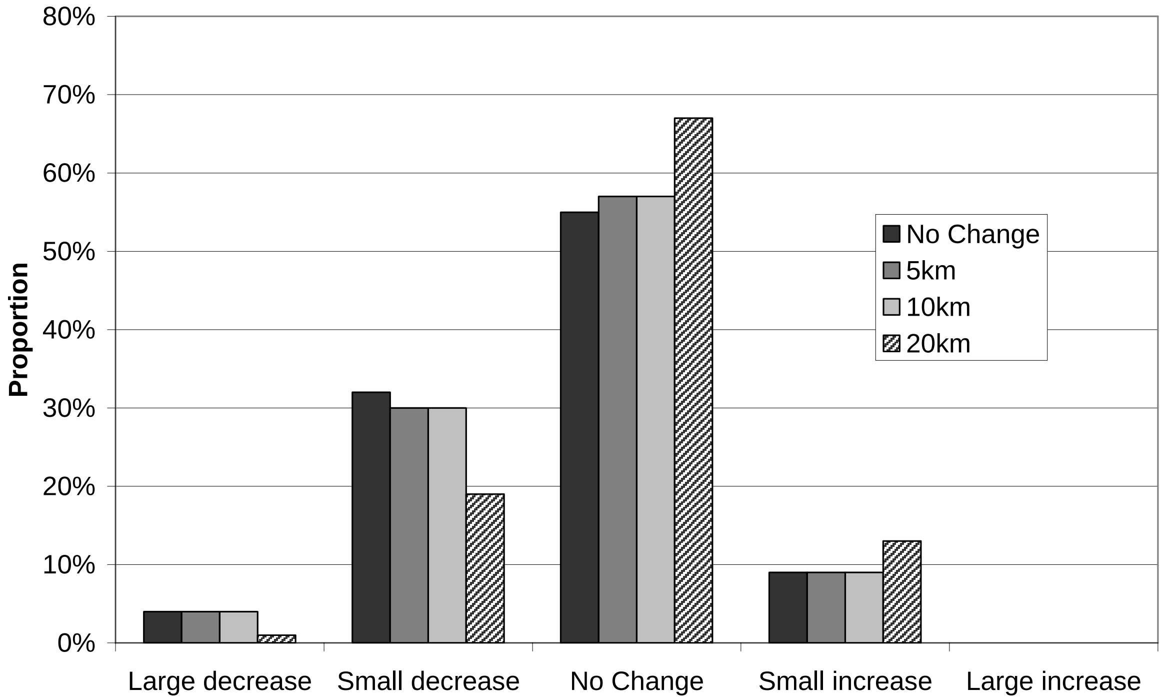

Figure 4. Impact of Riparian Management on Terrestrial Fauna

While the water quality and ecological ramifications of riparian management are not straightforward, economic costs associated with these activities are fairly clear. Both costs to council and to developers are expected to increase as a direct impact of these activities while recreational amenity is expected to suffer a small decrease due to the increase in pathogen levels in the lake.

Overall this scenario shows that the impacts of riparian management on water quality and ecological health may not be straightforward. These results showed no significant impact of riparian management on nutrients or suspended sediments, although this may be due to coarseness of the output states used to derive these results. Riparian management is expected to lead to increases in terrestrial fauna even for small increases in riparian vegetation. A small increase is seagrasses and saltmarsh was also predicted but only at under the largest amount of riparian revegetation. Even if positive impacts on these variables were found these would need to be offset against the negative impact of riparian management on pathogen levels. Care should be taken in using these results given the data quality underlying these results however they provide an interesting illustration of possible unforeseen negative consequences of management actions. Better information should be obtained to ensure these results accurately reflect the likely impacts of these management options. One result that was fairly clear and unlikely to be disputed was the increase in cost, both to developers and council, of implementing these revegetation options.

4.2 Sea level rise

Four sea level rise options were considered: no change, 2030, 2050 and 2100. These options represent projected sea levels during these years from climate change. Other climate change impacts such as increasing temperatures, storm surge or reduced rainfall are not considered. Twenty nodes were not impacted by this scenario: TN_input; TP_input; Pathogen_input; Population; Direct_Terrestrial_Vegetation_Impacts; Sedimentation_rate; Aesthetics; Dev_Costs; Domestic_Pets; Direct_Saltmarsh_Impacts; Domestic_Pets_Mgt; Direct_Riparian_Vegetation_Impacts; Weeds; pH_input; Boat_access; Fish_Passage; Flood_Risk; TSS_input; Direct_Mangrove_Impacts; and, pathogens_lake. In most cases this reflects the lack of any direct link between the node and sea level rise. In only a few cases, such as for lake pathogens, a link exists but no impact is experienced. Table 4 provides a summary of impacts on all other nodes.

Table 3. Summary of impacts of sea level rise

	2030	2050	2100
Water_Lvl	Moderate increase	Large increase	Very large increase
Algae_&_Phytoplankton	No impact	Moderate decrease	Large decrease
Rec_Amenity	No impact	Small increase	Moderate increase
Disaster_Costs	Moderate increase	Moderate to large increase	Large increase
Lake_Depth	Moderate increase	Moderate to large increase	Large increase
Saltmarsh	Small increase	Small to moderate increase	Moderate increase
Mozzies	Moderate increase	Moderate increase	Moderate increase
Migratory_Birds	Very small increase	Very small increase	Small increase
Seagrass	Moderate decrease	Moderate decrease	Moderate to large decrease
Salinity	No impact	Small increase	Moderate increase
cost_to_council	Small increase	Small increase	Moderate increase
Lake_Flushing	No impact	Small decrease	Moderate decrease
Freq_infra_flood	Moderate increase	Moderate to large increase	Large increase
Mangroves	No impact	Small decrease	Moderate decrease
TN_lake	No impact	Moderate decrease	Large decrease
TP_lake	No impact	Moderate decrease	Large decrease
TSS_lake	No impact	Very small decrease	Moderate decrease
pH_lake	No impact	No impact	Small increase
Aquatic_Fauna	Very small decrease	No impact	Very small increase
Terrestrial_Fauna	Small increase	Small increase	Small increase

This shows that impacts associated with lake level, such as flooding and disaster costs are likely to occur even for the smallest sea level rise scenario of 2030 change in lake level. This has consequences for seagrasses, decreasing their extent. Migratory brids and terrestrial fauna are expected to increase but only by a very small to small amount. Other impacts associated with lake flushing are not experienced until sea levels reach 2050 levels. Once these levels are reached flushing is expected to decrease (ie. time taken to exchange volume). This faster flushing then decreases lake pollutants such as TN, TP and TSS (although it has no noticeable impact on lake pathogens). It also reduces the extent of mangroves. The results for aquatic fauna are also interesting, showing signs of uncertainty in outcomes due to threshold effects. While these results should be used cautiously given the poor quality of data that underlies them, they do illustrate the difficulty of estimating the nature of change associated with a value that relies on a complex set of competing environmental outcomes. In this case it is difficult enough to be sure whether a change will lead to an increase or decrease in the value let alone accurately estimate the magnitude of such an effect.

Figure 5 shows the impacts of increased lake levels that are associated with sea level rise on the frequency of infrastructure flooding. This figure shows the gradual shift in frequency of infrastructure flooding given progressively higher lake levels. Under the base case the most likely option is considered to be a small decrease in costs. As sea level and consequently lake levels rise this goes from being no change to being a small increase. Under 2100 sea levels there is a greater than 10% change of a moderate increase in flooding frequency while there is a nearly 60% change of a small increase in the frequency of infrastructure flooding.

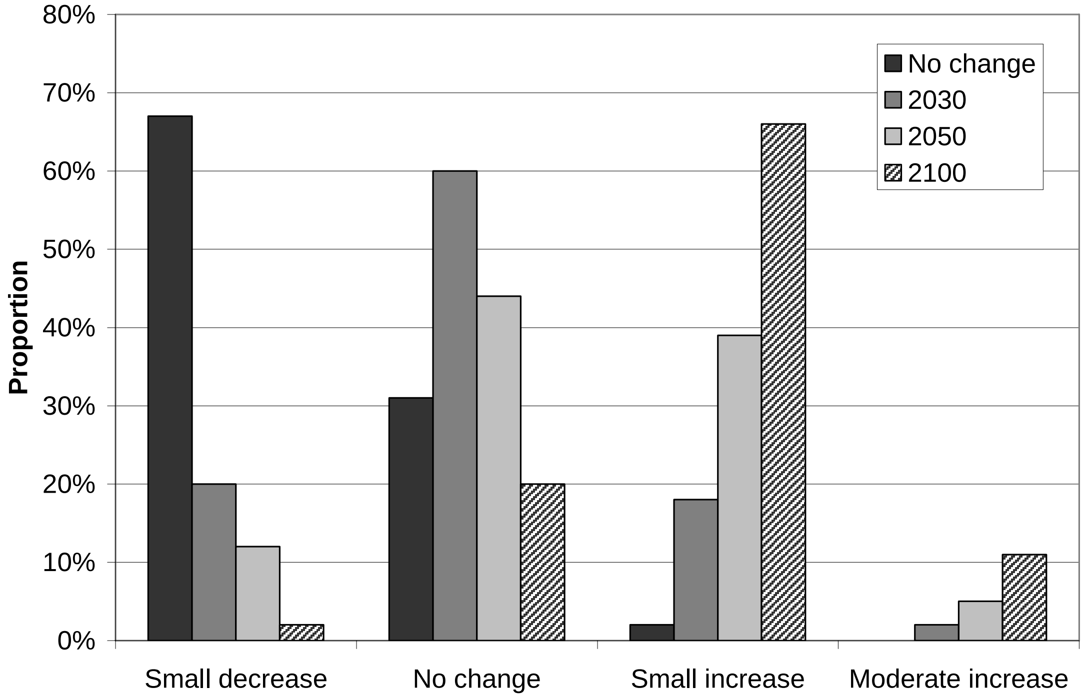

Figure 5. Impact of sea level rise on frequency of infrastructure flooding

As was suggested previously sea level rise impacts on other variables in two main ways: by increasing lake levels; and by decreasing the time it takes for the lake volume to be flushed or exchanged with the ocean. Figure 6 shows the impact of sea level rise on lake flushing. This figure shows that under 2030 levels no impact on lake flushing is expected. However past this level there is expected to be a significant decrease in flushing times. At the 2050 sea level the most likely outcome is that flushing times will be reduced by 1-5% while for the higher sea levels of 2100 a 5-10% reduction is most likely followed by a greater than 10% reduction.

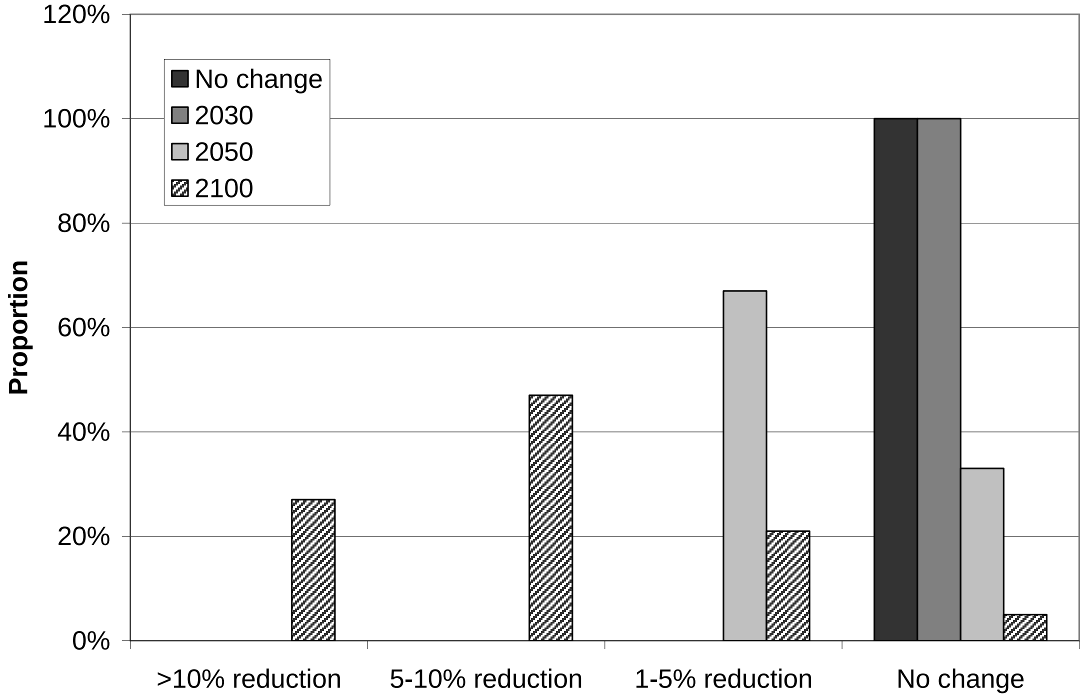

Figure 6. Impact of sea level rise on lake flushing

Both lake level and flushing have impacts on ecological attributes such as seagrass. This is because flushing affects algae and phytoplankton levels which are in competition for light and food resources with seagrasses while lake level affects light and the availability of suitable habitats for seagrasses. Figure 7 shows the impact of these changes on seagrasses. This shows that while no change is the most likely outcome under the base case, this shifts back to a small decrease as the most likely outcome once the sea reaches 2050 levels. The chances of both a small and a large decrease all increase under each of these options such that the worst outcome is expected for the greatest sea level rise (2100).

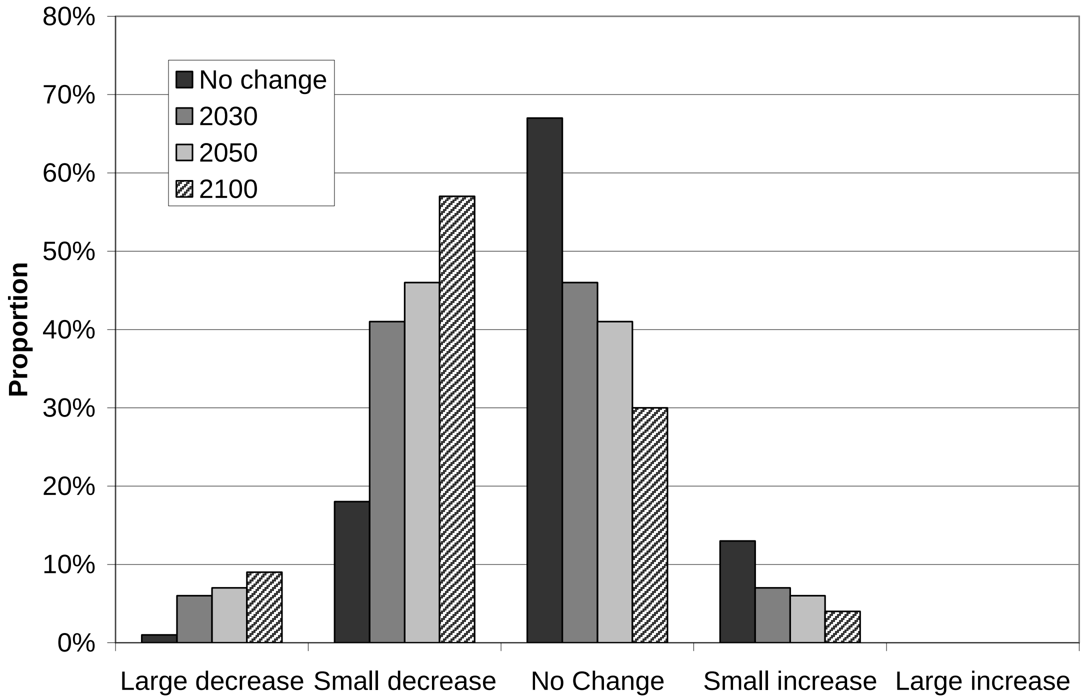

Figure 7. Impact of sea level rise on seagrass

By contrast algae and phytoplankton are affected only by flushing and not by lake levels. This influence comes through the impact of flushing on lake nutrient levels. This means that no change is expected in algae and phytoplankton under the 2030 option relative to the base case given that no change in flushing occurs for this option. Sea level rise is associated with decreases in nutrient concentrations for 2050 and 2100 options so that algae and phytoplankton are expected to decrease relative to the base case for these options. Under the base case the most likely option is that algae and phytoplankton will undergo a large increase while at 2050 levels this shifts back to being a small decrease. Under 2100 levels the most likely option is no change from current levels of algae and phytoplankton.

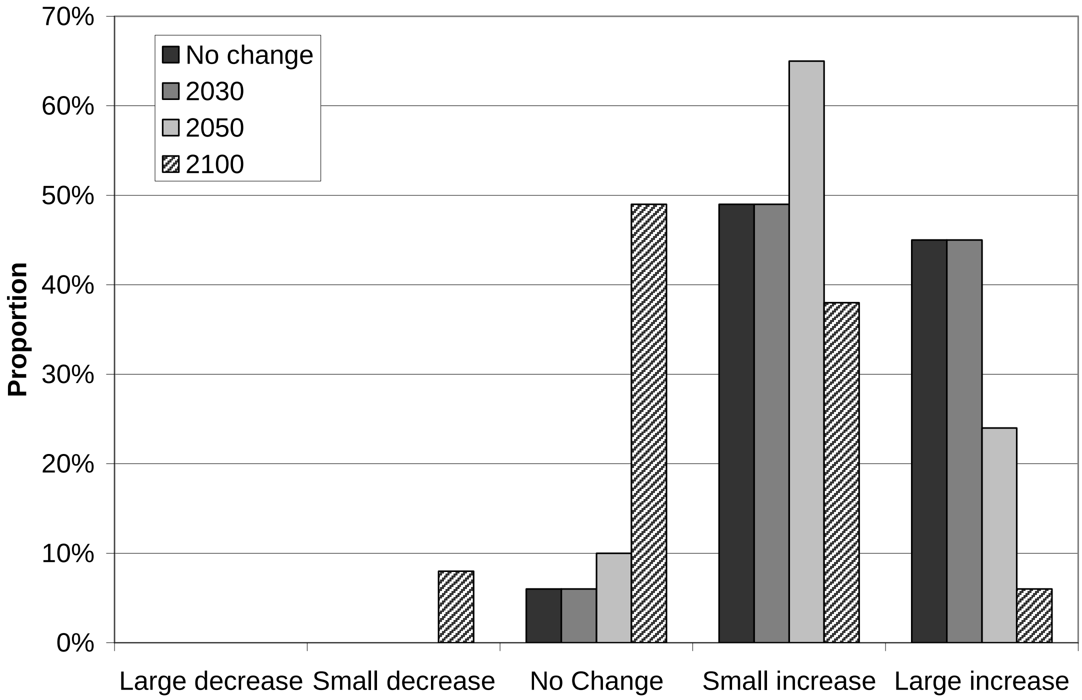

Figure 8. Impact of sea level rise of algae and phytoplankton

Overall these results show that sea level rise is associated with two primary impacts: an increase in lake water levels; and, a decrease in the time taken to flush the lake. Flushing was seen to be impacted only at 2050 or higher water levels (not 2030) while lake level was impacted for all sea level rise options. These impacts then have a range of follow-on impacts on the system. Increasing water levels generally increases flooding and the costs associated with it while reducing the area available for seagrass habitat given reduced light levels. Decreased flushing times are associated with a reduction in pollutants such as TN, TP and TSS and consequently can be expected to reduce seagrasses, algae and phytoplankton. It also reduces the extent of mangroves. The results for aquatic fauna showed the presence of threshold effects where one level of rise is associated with negative effects while others show no impact or even positive outcomes.

4.3 Community education

Only one alternative to the base case (no change) option exists for education. This option considers implementing a community education program. The model was run under these options. Results show that implementing an education program had no impact on 27 nodes: Water_Lvl; Disaster_Costs; Pathogen_input; Population; Direct_Terrestrial_Vegetation_Impacts; Lake_Depth; Sedimentation_rate; Mozzies; Aesthetics; Dev_Costs; Domestic_Pets; Salinity; Direct_Saltmarsh_Impacts; Direct_Riparian_Vegetation_Impacts; pH_input; Boat_access; Fish_Passage; Lake_Flushing; Flood_Risk; Freq_infra_flood; TSS_input; Mangroves; Direct_Mangrove_Impacts; TSS_lake; pH_lake; Aquatic_fauna; and, pathogens_lake. In most cases these nodes are not impacted because there is no direct link between them and community education. Community education is linked to water quality inputs: TN, TP, TSS and pathogens; as well as to domestic pet management and weeds. This shows that while a link exists between TSS input and community education, the effects of implementing the program on TSS are not expected to be large enough to be noticeable given the coarseness of the description of outputs for this scenario. Impacts on other nodes are summarised in Table 4.

Table 4. Summary of impacts of community education

	Implement program
Algae_&_Phytoplankton	Small decrease
TN_input	Moderate decrease
Rec_Amenity	Very small increase
TP_input	Small to moderate decrease
Migratory_Birds	Moderate increase
Seagrass	Very small increase
Domestic_Pets_Mgt	Moderate increase
Weeds	Moderate decrease
TN_lake	Small decrease
TP_lake	Small decrease
Terrestrial_Fauna	Small increase
Saltmarsh	Very small increase
cost_to_council	Moderate increase

These results show that community education is likely to have impacts on TN and TP inputs that are large enough to influence lake TN and TP (ie. concentrations once flushing has been accounted for). These pollutants both experience a small decrease in the lake. This leads to a small decrease in algae and phytoplankton which in turn leads to very small increases in seagrass and saltmarsh. Other impacts of education are direct impacts on the management of domestic pets and weeds. Reduced predation by domestic pets is in turn expected to lead to a moderate increase in migratory birds and a small increase in terrestrial fauna. Costs to council are also expected to increase by a moderate amount in implementing the program.

Figure 9 shows the impact of community education on total nitrogen concentrations in the Broadwater. This shows a 10% shift in probability from the highest category (>180µg/l) to the second highest category (170-180µg/l). The most likely outcome under both options is 170-180µg/l.

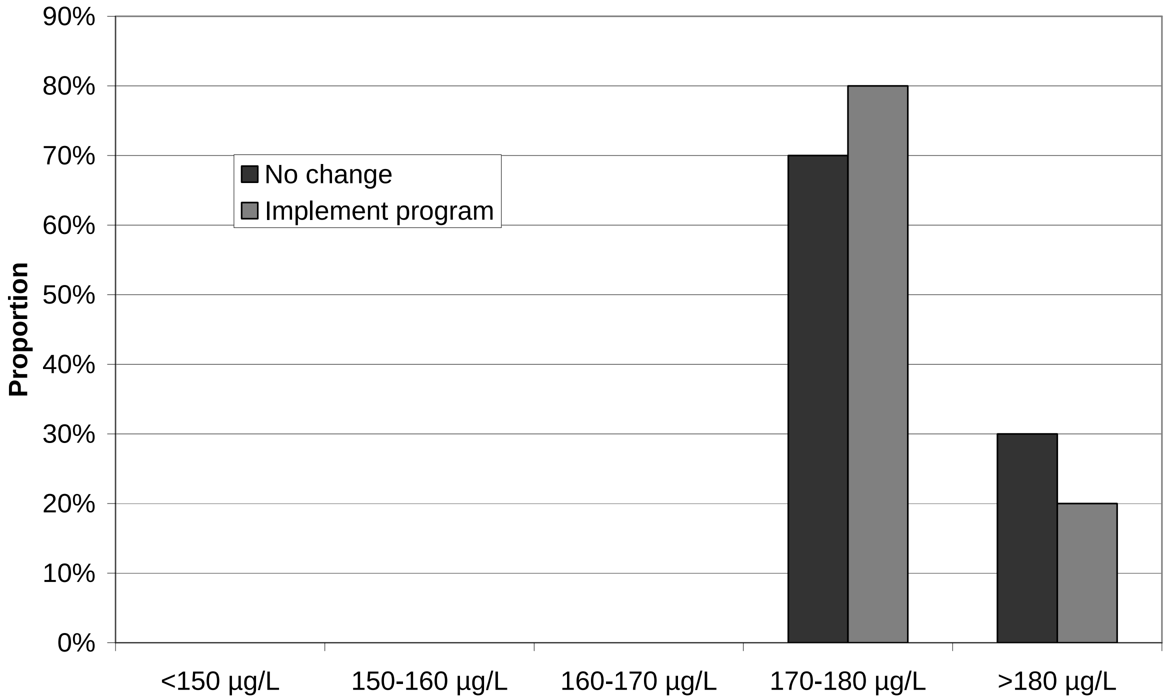

Figure 9. Impact of community education on Lake TN

The impacts on migratory birds of implementing a community education program are shown in Figure 10. This impact is realised by decreased predation and harassment of migratory birds by domestic pets following improvements in domestic pet management. This figure shows that education leads to an increase in migratory birds. Under the base case the most likely outcome is 'no change' but there is a substantial chance of a large (24%) or small decrease (16%). Under the community education program both these outcomes have reduced probability and the chances of no change and a small increase are improved.

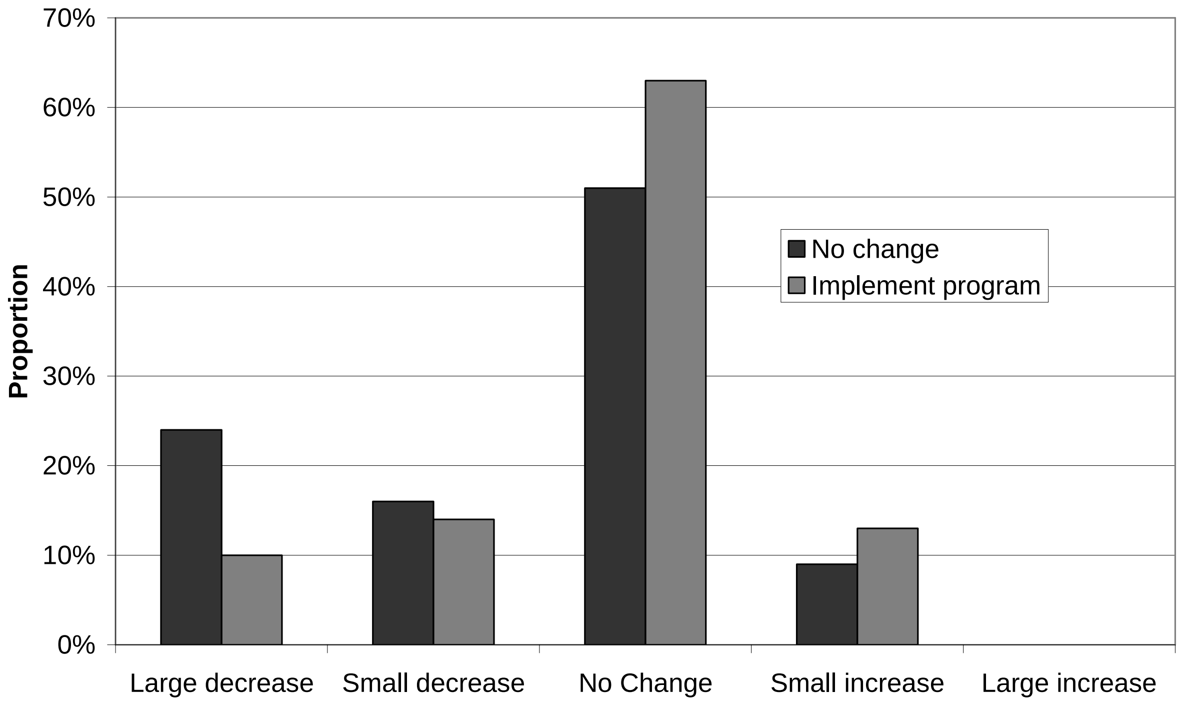

Figure 10. Impact of community education on migratory birds

Community education is also associated with improvements for terrestrial fauna. Figure 11 illustrates theses impacts. This figure shows that under both options 'no change' is the most likely outcome. However under the base case there is a substantial chance (>30%) of a small decrease in terrestrial fauna. When community education programs are introduced this is reduced to 11%. The chance of a large decrease is also removed. Both no change and a small decrease become more likely while there is also s small chance of a large increase under this option.

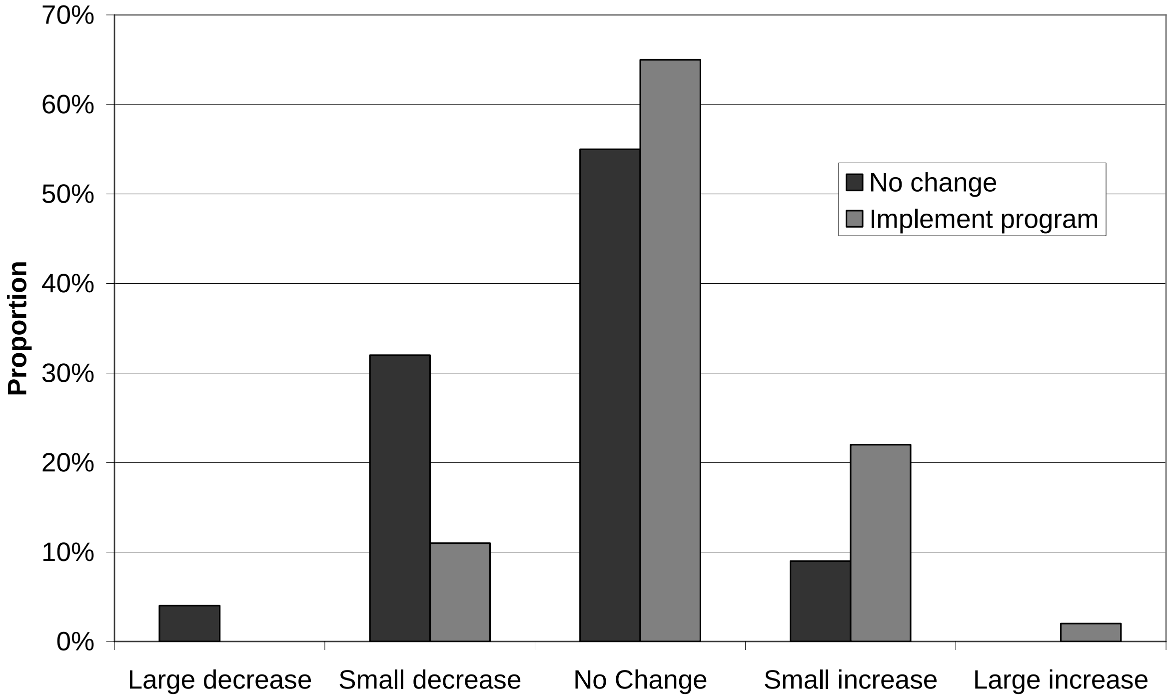

Figure 11. Impact of Community Education on Terrestrial Fauna

Overall these results show that community education can be associated with small improvements in water quality in terms of both nitrogen and phosphorus. These improvements are likely to reduce algae and phytoplankton which in turn has positive outcomes for seagrasses and saltmarsh, although these impacts can be expected to be quite small. Community education also has direct impacts on weeds and domestic pet management which in turn have benefits for migratory birds and terrestrial fauna. Thus it is likely that the greatest benefits of education programs will be on the terrestrial environment through changes in pet and weed management rather than on the aquatic environment through changes in water quality.

5 DISCUSSION OF THE RESULTS

This sustainability assessment report has provided a sample of results for riparian management, community education as well as of the impacts of sea level rise as a result of climate change. These options are a small subset of the total number of scenarios which can be considered by the Cobaki CLAM and as such do not provide conclusive evidence of the 'best' way forward from the options available. They are interesting in that they illustrate the potential for actions to improve the overall condition of the lake and catchment system.

These results show the impacts of two potential remediation alternatives: community education and riparian management; as well as the impact sea level rise as a result of human induced climate change. Riparian management is seen to have fairly mixed outcomes on water quality and ecology. Potential improvements in TN, TP and TSS were not realised in the results but riparian management was shown to lead to very substantial increases in pathogen levels as native fauna increased in these areas. This is also a positive for the catchment, improving outcomes for terrestrial fauna. A small increase is seagrasses and saltmarsh was also predicted but only at under the largest amount of riparian revegetation. Care should be taken in using these results given the data quality underlying these results however they provide an interesting illustration of possible unforeseen negative consequences of management actions. Better information should be obtained to ensure these results accurately reflect the likely impacts of these management options. If these results are accurate then they reflect the need to trade-offs increased costs to council and developers and increased pathogen levels as well as associated reductions in recreational amenity against increases in terrestrial fauna and very small improvements in other water quality and aquatic ecology outcomes.

Sea level rise was shown to be associated with two primary impacts: an increase in lake water levels; and, a decrease in the time taken to flush the lake. Flushing was seen to be impacted only at 2050 or higher water levels (not 2030) while lake level was impacted for all sea level rise options. These impacts then have a range of follow-on impacts on the system. Increasing water levels generally increases flooding and associated costs while reducing the area available for seagrass habitat given reduced light levels. Decreased flushing times are associated with a reduction in pollutants such as TN, TP and TSS and consequently can be expected to reduce seagrasses, algae and phytoplankton. Sea level rise also reduces the extent of mangroves. The results for aquatic fauna showed the presence of threshold effects where one level of rise is associated with negative effects while others show no impact or even positive outcomes. While these results are based on poor quality data and so should be used cautiously, this result illustrates the difficulties associated with estimating the nature of impacts on values that depend on a complex array of relationships with the environment.

Results for community education show that it can be associated with small improvements in water quality in terms of both nitrogen and phosphorus. These improvements are likely to reduce algae and phytoplankton which in turn has positive outcomes for seagrasses and saltmarsh, although these impacts can be expected to be quite small. Community education also has direct impacts on weeds and domestic pet management which in turn have benefits for migratory birds and terrestrial fauna. It was shown to be likely that the greatest benefits of education programs will be on the terrestrial environment through changes in pet and weed management rather than on the aquatic environment through changes in water quality. This reflects the result for riparian management also where water quality improvements were quite subtle and in the case of pathogens were expected to induce declining water quality but significant improvements were predicted for terrestrial fauna. When designing such programs it is important to be aware of the possibility of negative consequences for water quality as well as the likelihood that benefits may be best observed in the terrestrial environment. When assessing such programs some monitoring of terrestrial effects as well as those on water quality would be advisable to allow these benefits to be captured. Given the small nature of changes in water quality it is also unlikely that these types of programs could be used to offset the water quality effects of actions such as urban development unless these actions were expected to have very small impacts on water quality.

6 ACKNOWLEDGEMENTS

This project has been funded by the Northern Rivers Catchment Management Authority. The authors would particularly like to acknowledge the efforts of Roger Stanley of the CMA who has managed to project and provided considerable time and knowledge to this work. In addition the time and efforts of the project Reference Group need to be acknowledged. This group consisted of John Schmidt, Department of Natural Resources, Brian Hughes of Coastcare (initially), David Greenhalgh of the Solitary Islands Marine Park Authority, Marcus Riches of the Department of Primary Industries and Steve Jensen of the Department for

Planning. Finally this CLAM and subsequent results would not have been possible without the efforts of Tweed Council, in particular Tom Alletson.

7 References

Merritt, W.S., Ticehurst, J.L., and Rissik, D. (2006). Coastal Lake Assessment and Management (CLAM) Tool : User Guide. iCAM Technical Report 2006/02, Integrated Catchment Assessment and Management Centre, Australian National University, Canberra.

Merritt, W. , Letcher, R., and Ticehurst, J. (2006), Ensuring the sustainability of Coastal Lakes in NSW Northern Rivers: Coastal Lakes Assessment and Management (CLAM) Tool User Workshop, iCAM Technical Report 2006/04, Integrated Catchment Assessment and Management Centre, Australian National University, Canberra

Ticehurst, J.L., Merritt, W., and Rissik, D. (2006), Coastal Lakes Assessment and Management Tool: Application and tailoring workshop, iCAM Technical Report 2006/01, Integrated Catchment Assessment and Management Centre, Australian National University, Canberra

Ticehurst, J.L. Newham, L.H. T., Rissik, D., Letcher, R.A. and Jakeman A.J. (in press), A Bayesian network approach for assessing the sustainability of coastal lakes, *Environmental Modelling and Software.*

Whetton, P. and Holper, P. (2001), More droughts, more flooding rains, CSIRO Media release Reference: 2001/111, May 07 2001. downloaded 12/11/2004, http://www.csiro.au/index.asp?type=mediaRelesase&id=ClimateHotter.

APPENDIX 1. SUMMARY OF NODES IN THE COBAKI CLAM TOOL

Node	Description	Output States	Units
Foreshore aesthetics	Foreshore aesthetics	Decline, No change, Improve	
Algae and Phytoplankton	Frequency and severity of algae and phytoplankton blooms	Large Decrease, Small Decrease, No Change, Small Increase, Large Increase	
Aquatic fauna	Aquatic Fauna Biodiversity in Cobaki Broadwater	Large Decrease, Small Decrease, No Change, Small Increase, Large increase	
Boat access	Boat access to lake	decrease, no change, increase	
Cost to Council	Qualitative assessment of 'disaster' and 'development' costs to Council	no change, small increase, large increase	
Development costs	Qualitative representation of costs associated with developments and management actions	No Change, Small Increase, Moderate Increase, Large increase	
Direct mangrove impacts	Area of mangroves directly affected by development activities (rather than lake processes etc.)	Small Decrease, No Change, Small Increase	
Direct riparian vegetation impacts	Area of riparian vegetation directly affected by development activities (rather than lake processes etc.)	Large Decrease, Small Decrease, No Change, Small Increase, Large Increase	
Direct Saltmarsh impacts	Area of saltmarsh directly affected by development activities (rather than lake processes etc.)	Small Decrease, No Change, Small Increase	
Direct terrestrial vegetation impacts	Area of terrestrial vegetation directly affected by development activities	> 200 ha loss, 100 – 200 ha loss, 0 – 100 ha loss, no change, small increase	hectares
Disaster costs	Qualitative representation of costs associated with disasters	No Change, Small Increase, Large increase	
Domestic pets	Qualitative representation of changes in number of domestic pets in the catchment	No Change, small increase, large increase	
Domestic pet management	Qualitative changes in management of domestic pets in the catchment	No Change, small improvement, moderate improvement	
Fish passage	Qualitative changes in quality and extent of fish passage	Decline, No Change, Improve	

Flood risk	Qualitative representation of increased flooding risk associated with developments (note that this does not take into account rising water levels – see Frequency of Flooded Infrastructure)	Small Decrease, No Change, Small Increase, Moderate increase	
Frequency of flooded infrastructure	Qualitative representation of increased frequency of flooded infrastructure	Small Decrease, No Change, Small Increase, Moderate increase	
Lake depth	Qualitative representation of lake depth	Large Decrease, Small Decrease, No Change, Small Increase, Large Increase	
Lake flushing	Percentage change in the lake flushing exchange time	>10% Decrease, 10 - 5% Decrease, 5 - 0% Decrease, No Change	%
Mangroves	Qualitative representation of change in area of mangroves	Large Decrease, Small Decrease, No Change, Small Increase, Large Increase	
Migratory birds	Migratory Birds Biodiversity	Large Decrease, Small Decrease, No Change, Small Increase, Large increase	
Mosquitoes	Qualitative representation of change in impact of mosquitoes on residential populations	No Change, Small Increase, Moderate Increase	
Pathogen input	Quantitative representation of input of pathogens to Cobaki Broadwater	<14 , 14-150, 150-1000, >1000	cfu/100ml
Lake pathogen	The concentration of faecal coliforms in Cobaki Broadwater as CFU/100ml	<14, 14-150, 150-1000, >1000	cfu/100ml (CFU = colony forming units)
pH input	Qualitative representation of change in pH of inflows to Cobaki Broadwater	Decrease, No Change, Increase	
Lake pH	Qualitative representation of change in pH of Cobaki Broadwater	Decrease, No Change, Increase	
Population	Quantitative representation of change in population in the Cobaki Broadwater catchment	No Change, increase up to 10,000, increase up to 20,000, increase up to 30,000, increase over 30,000	

Recreational Amenity	Qualitative representation of change in recreational amenity provided by the Cobaki Broadwater	Large Decrease, Small Decrease, No Change, Small Increase, Large Increase	
Lake salinity	Change in the median lake salinity	<20.75, 20.75-21, 21-21.25, 21.25-21.5, 21.5-21.75, 21.75-22, >22	Practical Salinity Units (no units)
Saltmarsh	Qualitative representation of change in extent of saltmarsh in the Cobaki Broadwater catchment	Large Decrease, Small Decrease, No Change, Small Increase, Large Increase	
Seagrass	Qualitative representation of change in extent of seagrass in the Cobaki Broadwater	Large Decrease, Small Decrease, No Change, Small Increase, Large Increase	
Sedimentation rate	Qualitative representation of change in sedimentation rate of the Cobaki Broadwater	Large Decrease, Small Decrease, No Change, Small Increase, Large Increase	
Terrestrial fauna	Terrestrial Fauna Biodiversity	Large Decrease, Small Decrease, No Change, Small Increase, Large increase	
TN input	Inputs of total nitrogen to Cobaki Broadwater	<3000, 3000-6000, 6000-12000, >12000	kg/year
Lake TN	Total nitrogen in Cobaki Broadwater	<150, 150-160, 160-170, 170-180, >180	µg/L
TP input	Inputs of total phosphorus to Terranora Broadwater.	<2,000, 2,000-2,500, 2,500-3,000, 3,000-3,500, 3,500-4,000, 4,000-4,500, >4,500	kg/year
Lake TP	Total phosphorus in Cobaki Broadwater	<17, 17-18, 18-19, 19-20, >20	µg/L
TSS input	Inputs of total phosphorus to Terranora Broadwater	<40,000, 40,000-80,000, 80,000-120,000, 120,000-160,000, >160,000	kg/year
Lake TSS	Total suspended sediment in Cobaki Broadwater	<17, 17-18, 18-19, 19-20, >20	g/m^3
Lake water level	Quantitative representation in change in the lake water level (not "water depth" as termed in this model, as this is affected by sedimentation rate)	<1, 1 – 1.1, 1.1 – 1.2, 1.2 – 1.3, > 1.3	m

Weeds	Qualitative representation of change in weed coverage in the Cobaki Broadwater catchment	Large decrease, Small decrease, No Change, Small increase, Large increase	

Appendix 2. Additional scenario groups available in the Cobaki CLAM tool

1. 1C Land release
2. 2C Land release
3. Acid Sulfate Soil Management
4. Buffer Extent
5. Cobaki channel development
6. Cobaki Lakes
7. Domestic pet controls
8. Drain management
9. Dredging
10. Stormwater enforcement
11. Stormwater retrofitting
12. Tugun Bypass

1C Land release

Tweed shire Council has identified a number of parcels of land west of Cobaki Lake that may be suitable for rural residential living. They are zoned 1(c) Rural Living and are spread among rural lands and existing developments.

In total, the 1(c) areas are approximately 171.8 ha. Analysis of DNR existing land use maps (Baginska, 2004) indicates that of this area, 98.9 ha is bushland/riparian and 72.9 ha is unimproved pasture. Once developed it is considered to be low density.

2C Land release

Tweed shire Council has identified a number of parcels of land west of Cobaki Lake that may be suitable for small scale urban development. They are zoned 2(c) Urban Expansion and are spread among rural lands and existing developments.

In total, the 2(c) areas are approximately 218.7 ha. Analysis of DNR existing land use maps (Baginska, 2004) indicates that of this area, 0.2 ha is bare, 91.2 ha is bushland/riparian and 127.3 ha is unimproved pasture. Once developed it is considered to be medium density.

Acid Sulfate Soil Management

Increased effort in enforcing mitigation measures for acid releases from Acid Sulfate Soil was modeled. Such mitigation measures would include liming, bunding and reduced excavation depth, with enforcement measures including stricter development consent conditions, more frequent development inspections and increased ranger patrols.

No quantitative data was available to model the effects of this scenario, therefore an assumption of a moderately positive effect on "pH input" to the lake was assumed.

Buffer Extent

Tweed Shire Council currently requires a minimum vegetated buffer width of 40m between new developments and waterways. This scenario investigates the impact of increased capture efficiency associated with a doubling of the width of buffers.

Section 7.7.3 of the Environmental Impact Statement associated with the proposed upgrade of the Tweed West and Banora Point Water Reclamation Plants ((*Banora Point and Tweed Heads West WRP Reclaimed Water Management Strategy Environmental Impact Statement*, GHD (2004)) provides some indication of the capture rates associated with riparian planting. Based on those figures, the following estimates of capture rates for increased buffers were used in the model:

- TN – 15% captured
- TP – 20% captured
- TSS – 30% captured

Cobaki channel development
This is an area of 15.7 ha east of Cobaki Channel, just north of a small canal estate. It has water frontage of 400m. Currently the minimum setback required is 50m (total developable area of 13.9 ha), but options are provided for an increase of the buffer to 100m (total developable area of 12 ha).

It has not been determined if it will be industrial or residential development, therefore that option is provided also.

Analysis of DNR existing land use maps (Baginska, 2004) indicates that of the maximum developable area of 13.9 ha, 4.3 ha is bushland/riparian and 9.6 ha is unimproved pasture.

Cobaki Lakes
Cobaki Lakes is a large development of approximately 570 on the north western shore of Cobaki Lake. Current approvals will allow between 15,000 and 17,000 new residents. A hypothetical option provided here is for greater open space provision and low density limiting the population to 12,000. Within both population options there is also the option for greater protection of SEPP14 wetlands and an important eucalypt stand that provides unique goanna habitat.

Analysis of DNR existing land use maps (Baginska, 2004) indicates 59.2 ha of bushland/riparian and 510.8 ha of unimproved pasture

It is estimated that there will be around 351 ha of residential areas (including commercial precincts) and 219 ha of parks and golf courses.

Domestic pet controls
Reducing impacts on native fauna due to domestic pets was considered in terms of prohibiting domestic pets from new developments. (There is also a desire to model the positive impact on pathogen levels in the lake associated with a prohibition of pets in new developments, however the current pathogen model is unable to model this effect.)

No data was available to inform the model on the extent of the effect of this scenario. Prohibition of domestic pets in new developments was considered to lead to an "improved" state of "Domestic Pets Management" (which could also be achieved via the "Community Education" scenario), which in turn had a small effect on "Abundance and Diversity of Terrestrial Fauna".

Drain management
Recent years have seen enormous improvements in the management of agricultural drainage networks (primarily associated with cane farming) in order to limit acid and 'black-water' drainage events. However, it is thought that these works could be expanded further, although no *specific* details on the nature and extent of such works has been considered. A qualitative (and relatively small) increase in pH drainage to the lake has been assumed as a result of the "improved management" option.

Note that the final report for the Tweed River Estuary Ecosystem Health Monitoring Program 2000 to 2001 (University of Queensland Marine Botany Group, 2003) reports that the seasonal average for pH in the Cobaki Broadwater is "excellent".

Additionally, the "improved management" option is also associated with a slight improvement in "fish passage".

Dredging
The Cobaki Broadwater Management Plan (TSC, 1998) recommends dredging in the main body of the Broadwater. It suggests this will create suitable seagrass habitat whilst providing fill material for the airport expansion, and will improve tidal flushing and navigational access to Cobaki Creek (see the Opportunities diagram of the plan).

The plan recommends the development of a sensitive dredging plan to investigate enhancement of estuarine aquatic habitat and intertidal habitat for short legged wading birds.

Stormwater enforcement
The potential for reduced diffuse stormwater pollution via increased enforcement of existing stormwater regulations was considered. Such increased enforcement would be primarily be increased patrols by general council rangers, and possibly the introduction of a specific environmental ranger.

In the absence of quantitative data or advice from Tweed Shire Council on the extent, nature and/or effectiveness of increased enforcement effort an assumption of 5% reduction in pollutant (TN, TP and TSS) loads was assigned to this scenario.

Stormwater retrofitting
Modelling done as part of the Environmental Impact Statement associated with the proposed upgrade of the Tweed West and Banora Point Water Reclamation Plants ((*Banora Point and Tweed Heads West WRP Reclaimed Water Management Strategy Environmental Impact Statement*, GHD (2004)) indicated the principal driver of nitrogen and phosphorus concentrations in the system is stormwater runoff. As a result of this finding the EIS recommends that various 'catchment rehabilitation' measures be implemented to reduce diffuse pollutant loads, namely:

- Bioretention basins (vegetated swales and ponds that remove nutrients and sediment)
- Gross pollutant traps
- Restoration of riparian areas.

The pollutant load reductions associated with a combination of these measures were derived from ranges provided in the EIS. The model used the following estimates:

- TN – 75% captured
- TP – 33% captured
- TSS – 55% captured

These capture rates were applied under 2 arbitrary scenario options of stormwater retrofitting across 50% and 100% of existing urban developments.

Tugun Bypass
Construction and operation of the Tugun Bypass will result in the loss of 71.1 ha of habitat (45.2 ha lost, 25.9 ha edge affected) (Tugun Bypass EIS, vol. 1, main volume).