Urunga Lagoon Sustainability Assessment Report

December 2006

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CLIENT REPORT 2006/ 05

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

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Letcher, R., Birch, M., Merritt, W. ,Ticehurst, J. (2006). Urunga Lagoon Sustainability Assessment Report, December 2006, iCAM Client Report 2006/05, The Australian National University, Canberra, ACT.

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EXECUTIVE SUMMARY

This Sustainability Assessment report is based on results from the Coastal Lake Assessment and Management (CLAM) tool for Urunga lagoon. 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 Urunga Lagoon CLAM for each node and also provides an assessment of key data gaps identified by Mat Birch in putting the Urunga CLAM together. These gaps are:

- There is barely any tidal flushing and bathymetric data. Any attempt to rectify this could include an assessment of sea level rise impacts and the likely impact of removing the half tide training wall
- There is no data documenting sediment sources and movement for Urunga Lagoon. Dealing with sediment ingress is likely to be a major management issue in the future.
- A study of the likely effects of sea level rise and climate change on flood behaviour and the lagoon environment would be useful (including storm surge and coastal erosion of the dunal peninsula).
- The sampling regime for faecal coliforms should be expanded to include the less well flushed portions of the lagoon, particularly the SE corner and the confluence with Bruce's Creek.
- Long term monitoring of the runoff from the antimony processing plant (APP). Most data suggests there is very little runoff but the potential dangers for the aquatic environment and human health justify a detailed understanding of fluctuations and trends.
- Tourism has been identified as a value for Urunga Lagoon but little information exists detailing the lagoons influence on the tourism market. Bellingen Council has recently appointed a tourism officer so this will possibly be addressed through this position.

Three groups of scenario combinations were analysed: STP management in combination with management of the half tide training wall; the effects of climate change on flooding, shoaling, riparian vegetation and habitat; and, management of the former antimony processing plant. 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.

STP management with management of the half tide training wall
All STP management options were run in combination with options for management of the half tide training wall giving a total of 10 scenario combinations. These results show that these two scenario groups act together to protect water quality and ecological health of the lagoon. A deep ocean outfall and removal of the half tide training wall provide the best outcomes, both together and in isolation. The cost differences between the different options are substantial however. While a deep ocean outfall may be the preferable STP option for water quality outcomes this is also a very expensive option. Removal of the lower half tide training wall has a greater effect on water quality than any of the STP management options and is likely to lead to much greater ecological benefits even though it is the cheapest of the options presented.

Climate change
Under sea level rise estimates of 2030 no impacts are expected on any node. However once sea level rises beyond this point to 2050 and 2100 levels then significant impacts can be expected. Primary impacts of sea level rise are to increase both lagoon depth and lagoon levels, by a larger amount for the higher sea level rise option of 2100 than for 2050. This is turn leads to increased flooding as well as increased flushing of the estuary. Very small reductions are experienced on water quality parameters at the 2050 level while at the 2100 impacts are likely to be a moderate decrease. Water quality related outcomes such as exceedance of

ANZECC guidelines experience improvements while seagrasses, conservation values and tourism are shown to increase. It should be noted that this scenario considers sea level rise options only and does not consider the impacts of changes in rainfall, temperature and evaporation which would be likely to change at least some of these outcomes. The results show some indication of thresholds in the response of ecosystems, particularly in seagrasses. This means that while some changes may lead to an increase in the area or quality of a habitat for some level of change beyond this, substantial declines may be expected. Better understanding of these processes and their effects on the lake system are required. Local options to ameliorate some of these impacts should also be sought.

Management of the former antimony processing plant (APP)
Results for this scenario were limited by the lack of data on the effects of management options and their consequences for heavy metal accumulation on human health and the aquatic environment. Data should be collected to allow these impacts to be better quantified.

1 INTRODUCTION

This Sustainability Assessment report is based on results from the Coastal Lake Assessment and Management (CLAM) tool for Urunga Lagoon. 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 Urunga 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 assumption 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 CLAM 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 URUNGA CLAM

2.1 Conceptual framework

The Urunga Lagoon 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 total seagrass area are dependent on water quality parameters such as total suspended sediment or total nitrogen, which in turn depend on actions such as implementing new developments or the management of agricultural lands. Definitions of all nodes in the conceptual framework are given in Appendix 1.

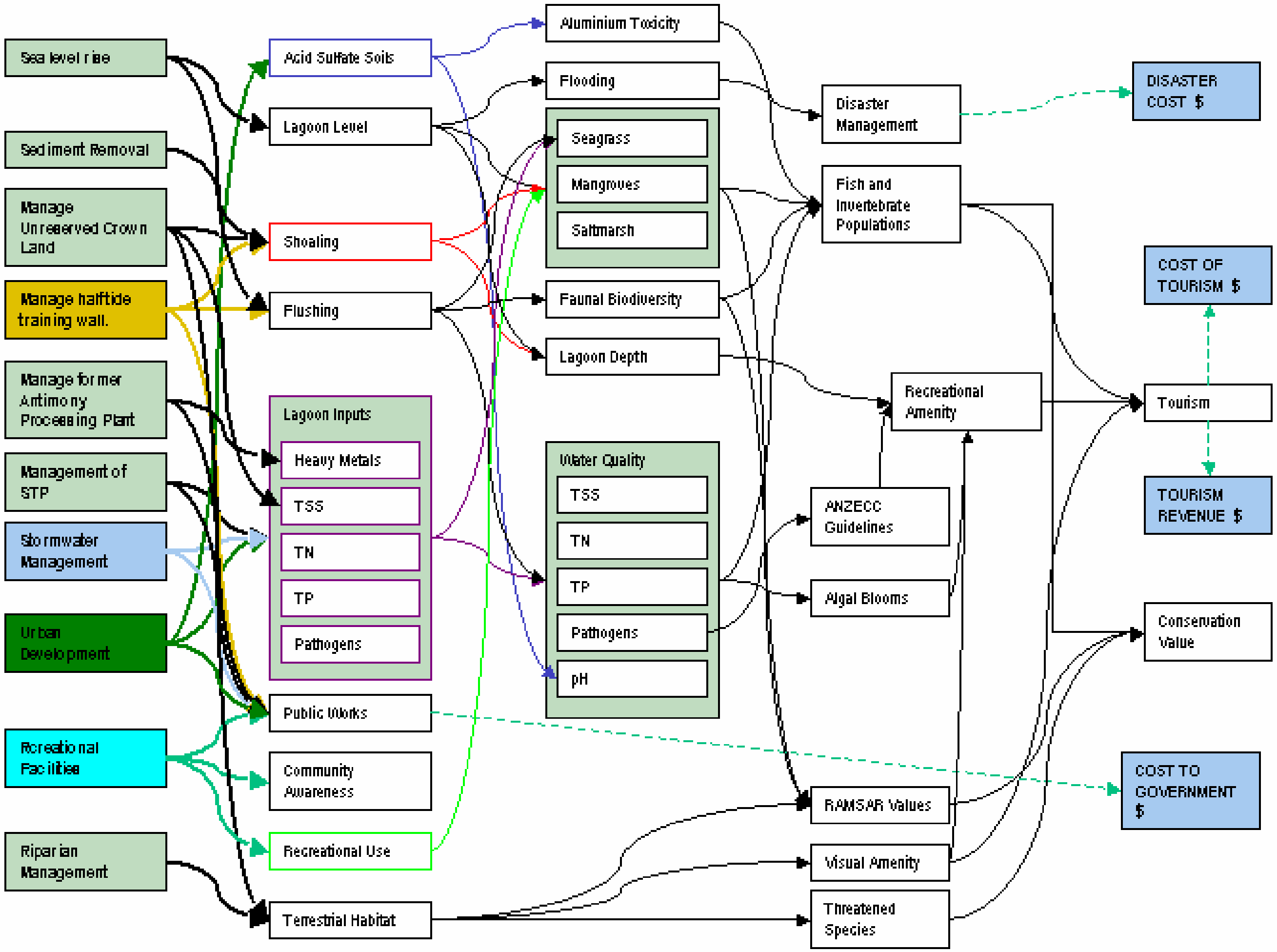

Figure 1. Urunga Lagoon conceptual framework

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. box in Figure 1). A statement of priority data collection needs for Urunga lagoon is then given. This statement was provided by Mat Birch who was put together the data for the Urunga CLAM.

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

Table 1. Data quality in the Urunga CLAM

Node	Quality of Data	Reason	Suggested improvements
Acid Sulfate Soil (ASS)	Average	ASS risk maps were used in conjunction with basic assumptions.	Smaller scale monitoring of acid risk and runoff and/or expert review of data.
Aluminium Toxicity	Average	Based on data interpretation and literature assumptions.	Locally based monitoring data and/or expert review of data
Algal Blooms	Average	Based on assumptions, some local data and knowledge also available.	More detailed modelling of algal response to changes in nutrients and sediments and/or expert review of data.
ANZECC Guidelines	Excellent	Based on definitions of ANZECC guidelines	No change.
Community awareness	Very poor	Based on unsupported assumptions.	Survey or interview to collect information on community awareness.
Conservation value	Poor	Based on assumptions and definitions.	Expert review of data and/or more detailed assessment of local conservation values and links to fish and invertebrate populations and RAMSAR values needed.
Cost of public works	Excellent	Based on actual estimates for each option from Council.	Expert review of results.
Cost of tourism	Poor	Based on unsupported assumptions and some local data.	Local data on the costs of tourism could be collected.
Disaster Cost	Average	Based on local data and unsupported assumption	Data on costs of flooding relative to the magnitude of flood events should be collected over time. Expert review of data.
Disaster Management	Average	Based on local data and assumptions.	Expert review of data.
Faunal biodiversity	Poor	Based on literature assumptions. No local data available.	Changes in faunal diversity could be monitored as a result of changes in flushing. Also baseline data would be good. Expert

			review of data.
Fish and invertebrate populations	Poor	Data based on literature supported assumptions. No local data available	Expert review. Base line data should be collected.
Flooding	Good	Based on local data and supported assumptions	Expert review of data.
Flushing	Average	Based on a simple uncalibrated model. Local data were used to run this model.	Expert review of data. Collection of improved bathymetry and topographical data would also assist.
Input heavy metals	Very poor	Based on local reports but results are not reported in a way where sensitivities are apparent.	More detailed description of heavy metal outcomes and more detailed assessment of impact of options on heavy metal movements.
Input pathogens	Good	Based on an uncalibrated model using good local data.	Expert review of data.
Input Total nitrogen	Good	Based on an uncalibrated model using good local data.	Expert review of data. Impact of climate change on stormwater to be incorporated
Input total phosphorous	Good	Based on an uncalibrated model using good local data.	Expert review of data. Impact of climate change on stormwater to be incorporated
Input Total Suspended Solids	Good	Based on an uncalibrated model using good local data.	Expert review of data. Impact of climate change on stormwater to be incorporated
Lagoon Depth	Poor	Based on assumptions.	Bathymetry and more detailed topography data for the lake foreshore is required.
Lagoon level	Poor	Based on assumptions.	Monitoring of relationship between levels in the lagoon and the ocean.
Mangroves	Average	Based on literature assumptions	Mapping of current mangrove extent and lagoon bathymetry would produce better results. Expert review of data.
pH	Average	Based on some local data and assumptions	Expert review of data. More detailed modelling of effect of changes in runoff and flushing on lake pH.
Public Works	Good	Based on local knowledge and data provided by Council.	Expert review of data required.
Ramsar Values	Good	Based on RAMSAR criteria and baseline data.	Expert review of data
Recreational amenity	Very poor	Derived from assumptions. No local data available.	Local data on recreational uses and values associated with these of the lagoon.
Recreational use	Very poor	Derived from assumptions. No local data available.	Local data on recreational uses and values associated with these of the lagoon.

Saltmarsh	Average	Based on literature assumptions. No local data available.	Expert review of data. Data collection on the extent or saltmarsh and depth profile of the lagoon would also be useful.
Seagrass	Average	Based on literature assumptions	Mapping of current seagrass extent and lagoon bathymetry would produce better results. Expert review of data.
Shoaling	Average	Based on assumptions and local study	Expert review of data.
Terrestrial habitat	Poor	Based on unsupported assumptions. No local data available	Mapping of extent and quality of terrestrial habitat. Expert review of results.
Tourism	Average	Based on unsupported assumptions. Some local data available.	Expert review of data.
Tourist revenue	Poor	Based on assumptions and limited local data.	Local data on tourist revenue from the lagoon could be collected by surveying users.
Visual amenity	Very poor	Based on unsupported assumptions	Local data collection on visual amenity values derived from the lagoon.
WQ Pathogen	Average	Uses a simple uncalibrated model derived from other situations. Model has been run with local data.	Expert review of data. Collection of improved bathymetry and topographical data would also assist. More detailed modelling of flushing impacts on pathogens and monitoring of levels in the lagoon could also be undertaken.
WQ Total Nitrogen	Average	Uses a simple uncalibrated model derived from other situations. Model has been run with local data.	Expert review of data. Collection of improved bathymetry and topographical data would also assist. More detailed modelling of flushing impacts on nitrogen and monitoring of levels in the lagoon could also be undertaken.
WQ Total Phosphorous	Average	Uses a simple uncalibrated model derived from other situations. Model has been run with local data.	Expert review of data. Collection of improved bathymetry and topographical data would also assist. More detailed modelling of flushing impacts on phosphorus and monitoring of levels in the lagoon could also be undertaken.
WQ Total Suspended Solids	Average	Uses a simple uncalibrated model derived from other situations. Model has been run with local data.	Expert review of data. Collection of improved bathymetry and topographical data would also assist. More detailed modelling of flushing impacts on total suspended solids and monitoring of levels in the lagoon could also be undertaken.

Priority data collection areas identified by Mat Birch are:

- There is barely any tidal flushing and bathymetric data. Any attempt to rectify this could include an assessment of Sea Level Rise impacts and the likely impact of removing the half tide training wall

- There is no data documenting sediment sources and movement for Urunga Lagoon. Dealing with sediment ingress is likely to be a major management issue in the future.
- A study of the likely effects of Sea Level Rise and climate change on flood behaviour and the lagoon environment would be useful (including storm surge and coastal erosion of the dunal peninsula).
- The sampling regime for faecal coliforms should be expanded to include the less well flushed portions of the lagoon, particularly the SE corner and the confluence with Bruce's Creek.
- Long term monitoring of the runoff from the antimony processing plant. Most data suggests there is very little but the potential dangers for the aquatic environment and human health justify a detailed understanding of fluctuations and trends.
- Tourism has been identified as a value for Urunga Lagoon but little information exists detailing the lagoons influence on the tourism market. Bellingen Council has recently appointed a tourism officer so this will possibly be addressed through this position.

3 Scenarios

In order to develop this Sustainability Assessment analysis a relatively small subgroup of scenarios were selected from the 103,680 available in the Urunga CLAM. In was decided to focus on the following scenarios:

- STP management in combination with management of the half tide training wall;
- The effects of sea level rise due to climate change on flooding, shoaling, riparian vegetation and habitat; and,
- Management of the former antimony processing plant.

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 STP management

The STP has been recently upgraded to include active UV treatment of effluent. Further upgrades that would have an impact on the lagoon include the diversion of sewage through an artificial wetland or extension of the outfall offshore. The sewage treatment plant is currently running far below its licensed capacity. This scenario explores the effects of further upgrades to the sewage treatment plant and increased load on the sewage treatment plant.

3.2 Management of the Half Tide Training Wall (HTTW)

The half tide training wall limits the tidal flushing of Urunga Lagoon and may act as a trap for sediment. This scenario investigates the action of lowering the level of the half tide training wall to Mean Low Water Spring.

3.3 Sea level rise

The sea level is predicted to rise in the future due to climate change. Using data based on CSIRO Atmospheric Sciences (Sept 2004), predicted changes is sea level for the years 2050 and 2100 will be modelled.

3.4 Management of the former antimony processing plant

The former APP site is a potential source of heavy metals in the lagoon catchment. The risk of heavy metal mobilisation could be greatly reduced by the management of this site. This scenario explores a variety of management options that would reduce the risk of heavy metal contamination of Urunga Lagoon.

4 Results from Scenario Runs

4.1 STP management and Management of the half tide training wall

These two options were run in combination, giving a total of 10 scenarios including the "No change" option. Table 2 provides a summary of impacts on all nodes for which there was an impact of these scenarios. It should be noted that this impact is relative to the base case such that an "increase" is a greater probability of a higher value option. So for example if a node was likely to decrease in value under the base case, "increase" in the table below implies that the node will have a high probability of a greater value. This might still mean that that the node will decrease but may not decrease by as great an amount as the base case or it may indicate that the node will in fact increase.

Table 2. Summary of impacts of STP management and management of the half tide training wall

	Redirect Outfall Through Artificial Wetland	Redirect Outfall to Deep Ocean	Recycle Treated Effluent	Maximum Capacity	Lower HTTW	Lower HTTW, Artificial Wetland	Lower HTTW, Deep Ocean	Lower HTTW, Recycle	Lower HTTW, Maximum Capacity
Flushing	No impact	No impact	No impact	No impact	Moderate increase	Moderate increase	Moderate increase	Moderate increase	Moderate increase
Shoaling	No impact	No impact	No impact	No impact	Large decrease	Large decrease	Large decrease	Large decrease	Large decrease
Input Total Phosphorus	Large decrease	Very large decrease	Moderate to large decrease	Large increase	No impact	Large decrease	Very large decrease	Moderate to large decrease	Large increase
Input Total Nitrogen	Large decrease	Very large decrease	Moderate decrease	Moderate increase	No impact	Large decrease	Very large decrease	Moderate decrease	Moderate increase
Public Works	Less than $200000	Less than $1000000	Less than $500000	No cost	Less than $100000	Less than $300000	Less than $1250000	Less than $750000	Less than $100000
Mangroves	No impact	No impact	No impact	No impact	Moderate decrease	Moderate decrease	Moderate decrease	Moderate decrease	Moderate decrease
Lagoon Depth	No impact	No impact	No impact	No impact	Moderate increase	Moderate increase	Moderate increase	Moderate increase	Moderate increase
WQ Total Suspended Solids	No impact	No impact	No impact	No impact	Large decrease	Large decrease	Large decrease	Large decrease	Large decrease
Faunal Biodiversity	No impact	No impact	No impact	No impact	Moderate increase	Moderate increase	Moderate increase	Moderate increase	Moderate increase
WQ Total Nitrogen	Very small decrease	Very small decrease	Very small decrease	No impact	Large decrease	Large decrease	Large decrease	Large decrease	Large decrease
WQ Pathogens	No impact	No impact	No impact	No impact	Large decrease	Large decrease	Large decrease	Large decrease	Large decrease
WQ Total Phosphorus	Very small decrease	Very small decrease	Very small decrease	Very small increase	Large decrease	Large decrease	Large decrease	Large decrease	Large decrease

RAMSAR Values	Very small increase	Small increase	Very small increase	Very small decrease	Moderate increase	Moderate increase	Moderate to large increase	Moderate increase	Moderate increase
Fish and Invertebrate Populations	Small to moderate increase	Moderate to large increase	Small to moderate increase	Small decrease	Moderate increase	Moderate to large increase	Large increase	Moderate to large increase	Small to moderate increase
Recreational Amenity	No impact	No impact	No impact	No impact	Large increase	Large increase	Large increase	Large increase	Large increase
ANZECC Guidelines	No impact	No impact	No impact	No impact	Large improvement	Large improvement	Large improvement	Large improvement	Large improvement
Algal Blooms	Very small decrease	Very small decrease	No impact	Very small increase	Very large decrease	Very large decrease	Very large decrease	Very large decrease	Very large decrease
Tourism	No impact	No impact	No impact	No impact	Large increase	Large increase	Large increase	Large increase	Large increase
Conservation Value	No impact	Small increase	No impact	No impact	Moderate increase	Moderate increase	Moderate to large increase	Moderate increase	Moderate increase
Seagrass	Very small increase	Moderate increase	Very small increase	Very small increase	Moderate increase	Moderate increase	Large increase	Moderate increase	Moderate increase

Nodes for which there was no impact are: Al Toxicity; Acid Sulfate Soils; Lagoon Level; Input Heavy Metals; Input Total Suspended Solids; Input Pathogens; Terrestrial Habitat; Community Awareness; Recreational Use; Saltmarsh; pH; Flooding; Visual Amenity; and, Disaster Management. These are largely as would be expected given the linkages in the CLAM tool.

The table shows that management of the lower half tide training wall will have significant impacts on flushing of the estuary. The model indicates a large decrease in shoaling as a result of this action as well as a moderate increase in lagoon depth. These changes have significant effects on lagoon water quality leading to a large decrease in estuary TN, TP, TSS and pathogens. These effects on water quality are stronger than those brought about by management of the STP, although there is evidence that there are cumulative effects on lagoon ecology from the combination of both sets of actions. The effects on estuary TP are shown in more detail in Figure 2.

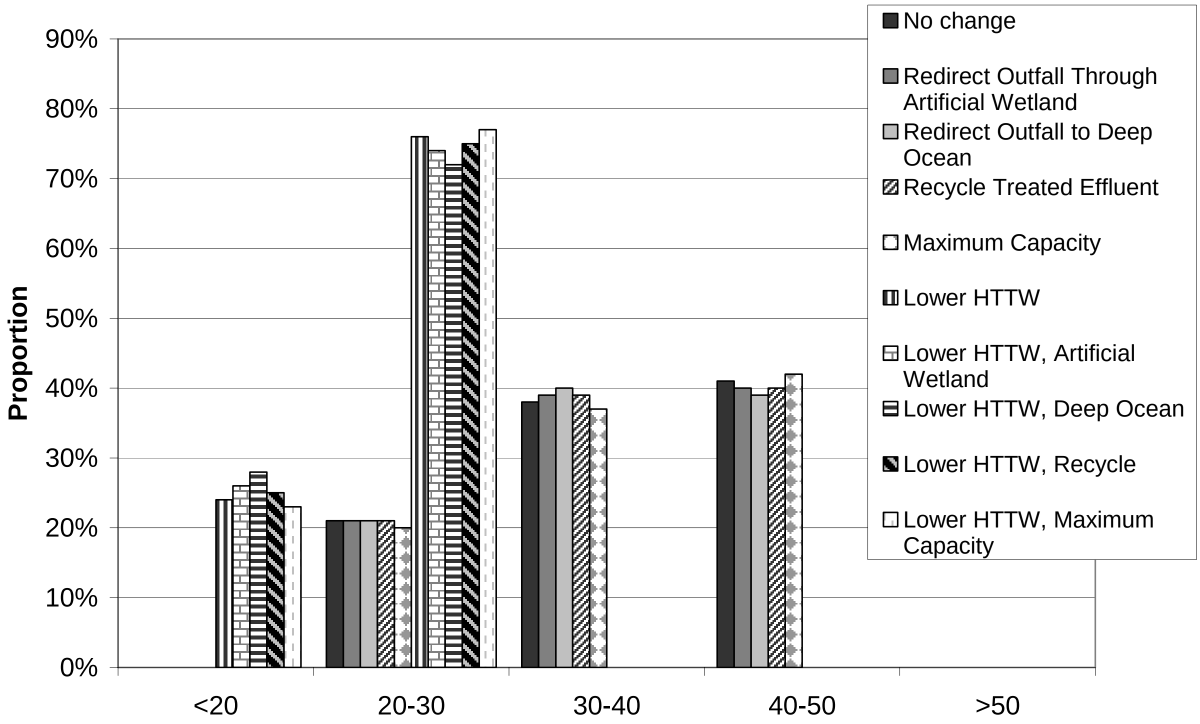

Figure 2. Impact of STP management and management of the lower half tide training wall on estuary total phosphorus (µg/L)

This figure shows that without change to the lower half tide training wall, management of the STP is unlikely to greatly affect total phosphorus levels in the lagoon. A fairly small decrease in estuary TP can be expected where a deep ocean outfall is used. Recycling treated effluent or re-directing outfalls through an artificial wetland may lead to a small decrease in estuary TP. Increased loads to the STP under the Maximum Capacity option results in a small increase in estuary TP concentrations. Removing the half tide training wall will significantly reduce estuary TP levels such that the most frequent or probable concentration of TP becomes 20-30 µg/L for all STP management options. In the no change option, the most probable concentration range was 40-50 µg/L. Differences between STP management options become more apparent once the lower half tide training wall is removed. The option of deep ocean outfall clearly produces the lowest concentration of estuary TP, while recycling effluence and directing effluent through artificial wetlands will have similar effects, reducing estuary TP but by a smaller amount. With the removal of the lower half tide training wall, the most frequent TP concentration range is 20-30 µg/L.

These types of effects become more apparent in studying the impacts of these scenarios on ecological outcomes in the estuary. While the impacts of STP management on water quality were relatively subtle, these will lead to significant ecological improvements. The differences between STP management options also become more apparent. The use of a deep ocean outfall is likely to lead to a moderate increase in seagrass beds, small to very small improvements in algal blooms and conservation values, and moderate to large increase in fish and invertebrate populations. Other options have little impact on these outcomes, although seagrasses experience a very small increase, and fish and invertebrate populations show small to moderate increases under other STP management options. Increasing loads to the STP to maximum capacity leads to a very small to small decline in seagrass and fish and invertebrate populations as well as a very small increase in algal blooms. Management of the lower half tide training wall leads to much more noticeable impacts, including large to moderate increases in seagrass and fish and invertebrate populations and very large decreases in algal blooms. The impact of these scenarios on fish and invertebrate populations is shown in more detail in Figure 3.

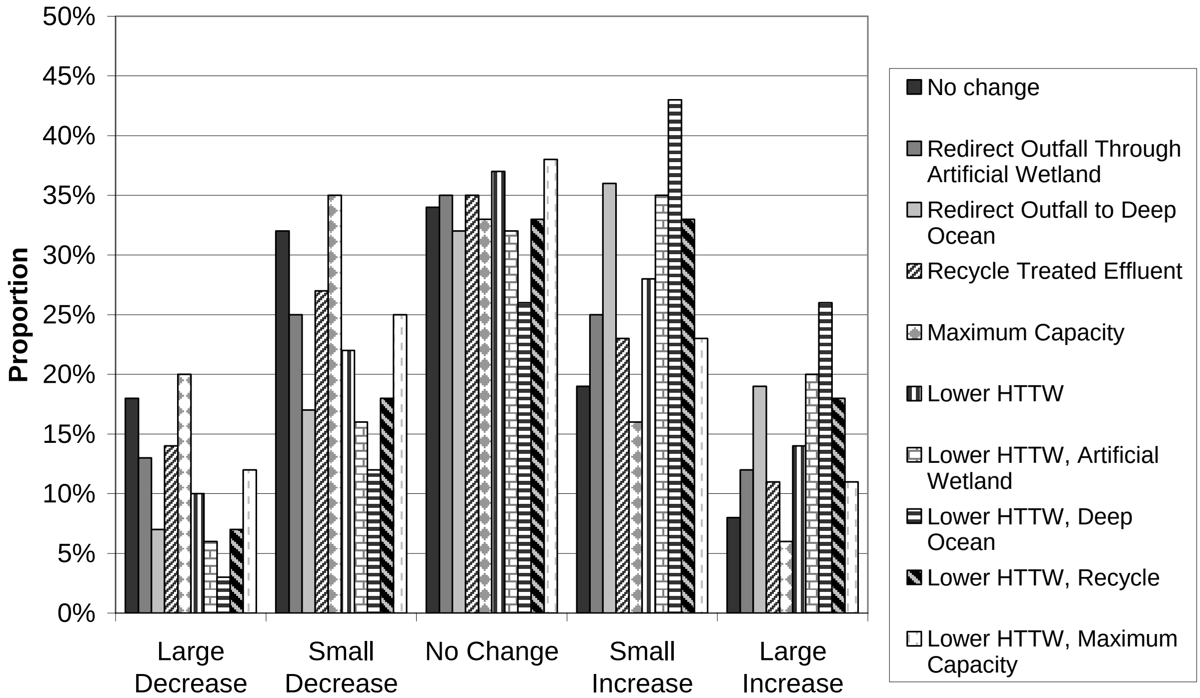

Figure 3. Impact of STP management and management of the lower half tide training wall on fish and invertebrate populations

This figure shows that the greatest increase in populations is experienced when the lower half tide training wall is removed and outfall is redirected to the deep ocean. Interestingly redirecting the outfall without removing the half tide training wall leads to a similar, if slightly smaller, increase in fish and invertebrate populations compared to other options where the wall is removed. Impacts of other STP management options in isolation are much more subtle but still act to increase populations. The effect of these actions on seagrasses is demonstrated in detail in Figure 4.

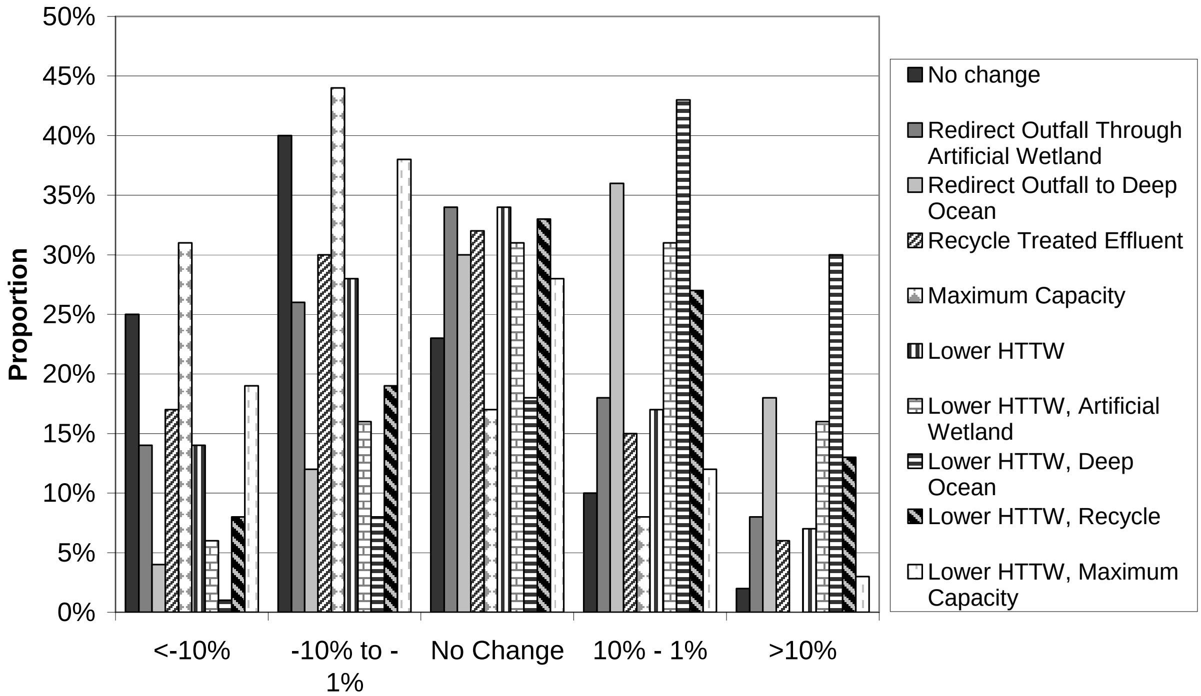

Figure 4. Impact of STP management and management of the lower half tide training wall on seagrasses

This figure also shows the greater benefits of the deep ocean outfall option on seagrass habitat versus other STP management options. Both with and without removal of the half tide training wall this option leads to significant improvements beyond those of other STP management options. The effect of this option is not as great however if the half tide training wall is removed, showing there is less difference with other STP management options in this case. Again redirecting outfall to artificial wetlands or recycling treated effluent are shown to be better options than ‘no change’ or ‘maximum capacity’ when the half tide training wall is not removed. The same trend is seen for the STP management actions when the wall is removed although the benefits are much larger.

Overall these results show that these two scenario groups act together to protect water quality and ecological health of the lagoon. A deep ocean outfall and removal of the half tide training wall provide the best outcomes, both together and in isolation. The cost differences between the different options are substantial however. Cost estimates of these difference options are shown in Table 3 below.

Table 3. Summary of costs for STP management options and removal of the half tide training wall

	Approximate cost
No change	$0
Redirect Outfall Through Artificial Wetland	$170,000
Redirect Outfall to Deep Ocean	$880,000
Recycle Treated Effluent	$460,000
Maximum Capacity	$0
Lower HTTW	$100,000
Lower HTTW, Redirect outfall through Artificial Wetland	$260,000
Lower HTTW, Redirect outfall to deep ocean	$1,140,000
Lower HTTW, Recycle treated effluent	$670,000
Lower HTTW, Maximum Capacity	$100,000

It should be noted that due to the calculation method whereby cost outcomes are attributed to broad bands of cost (eg. a histogram) these costs are approximate. For example costs are additive but the cost of recycled effluent is estimated at $460,000 and removal of the HTTW is $100,000. This would lead to an expected value of $560,000 when these two options are considered together. The calculation method gives this value as $670,000 instead. The important thing to note is the relative magnitude of costs which remain correct.

Overall this table shows that while a deep ocean outfall may be the preferable STP option for water quality outcomes this is also a very expensive option. Interestingly removal of the lower half tide training wall has a greater effect on water quality than any of the STP management options and is likely to lead to much greater ecological benefits even though it is the cheapest of the options presented.

4.2 Sea level rise

Sea level rise options were run in isolation and their impacts considered for all nodes. Table 4 summarises the impacts of climate change on all nodes for which there was an impact. Unimpacted nodes were: Al Toxicity; Acid Sulfate Soils; Shoaling; Input Heavy Metals; Input Total Suspended Solids; Input Total Phosphorus; Input Total Nitrogen; Input Pathogens; Public Works; Terrestrial Habitat; Community Awareness; Recreational Use; pH; and, Visual Amenity.

Table 4. Summary of impacts of sea level rise

	2030	2050	2100
Lagoon Level	No impact	Moderate increase	Large increase
Flushing	No impact	Very small increase	Moderate increase
Mangroves	No impact	Small decrease	Small to moderate decrease
Saltmarsh	No impact	Small decrease	Moderate decrease
Flooding	No impact	Moderate increase	Large increase
Lagoon Depth	No impact	Small increase	Moderate increase
WQ Total Suspended Solids	No impact	Very small decrease	Moderate decrease
Faunal Biodiversity	No impact	Very small increase	Moderate increase
WQ Total Nitrogen	No impact	Very small decrease	Moderate decrease
WQ Pathogens	No impact	Very small decrease	Moderate decrease
WQ Total Phosphorus	No impact	Very small decrease	Moderate decrease
RAMSAR Values	No impact	Very small decrease	Very small increase
Disaster Management	No impact	Moderate increase	Large increase
Fish and Invertebrate Populations	No impact	Small decrease	Small increase
Recreational Amenity	No impact	Very small increase	Moderate increase
ANZECC Guidelines	No impact	Very small improvement	Moderate improvement
Algal Blooms	No impact	Very small decrease	Large decrease
Tourism	No impact	Very small increase	Moderate increase
Conservation Value	No impact	Very small decrease	Small increase
Seagrass	No impact	Small decrease	Small increase

This table shows that under sea level rise estimates of 2030 no impacts are expected on any node. However once sea level rises beyond this point to 2050 and 2100 levels then significant impacts can be expected. Primary impacts of sea level rise are to increase both lagoon depth and lagoon levels, by a larger amount for the higher sea level rise option of 2100 than for 2050. This is turn leads to increased flooding as well as increased flushing of the estuary. Very small reductions are experienced on water quality parameters at the 2050 level while at the 2100 impacts are likely to be a moderate decrease. Water quality related outcomes such as exceedance of ANZECC guidelines experience improvements while seagrasses, conservation values and tourism are shown to increase. It should be noted that this scenario considers sea level rise option only and does not consider the impacts of changes in rainfall, temperature and evaporation which would be likely to change at least some of these outcomes.

Figures 5 to 7 show the impact of climate change on mangroves, saltmarshes and seagrasses respectively.

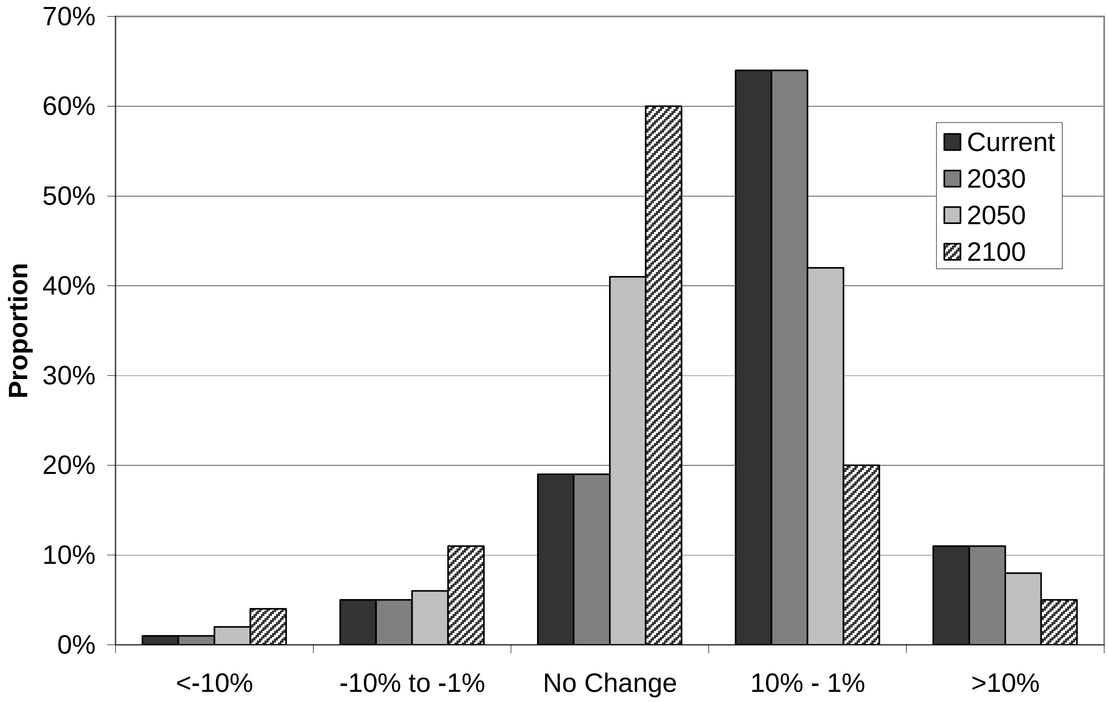

Figure 5. Impact of sea level rise options on mangroves

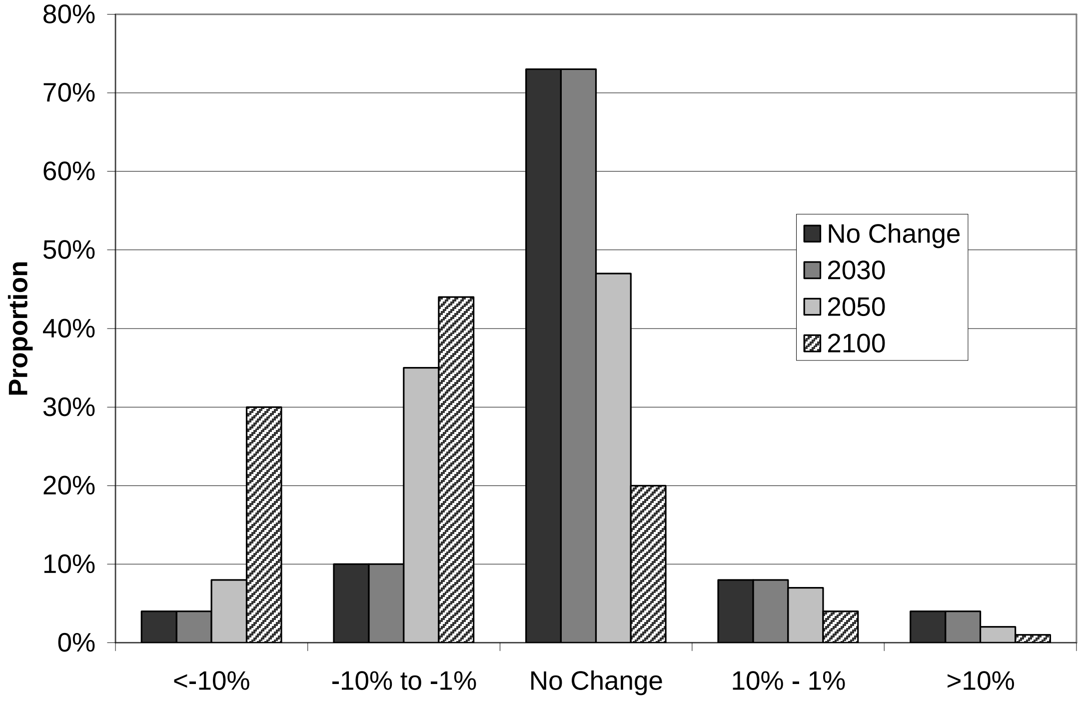

Figure 6. Impact of sea level rise options on saltmarshes

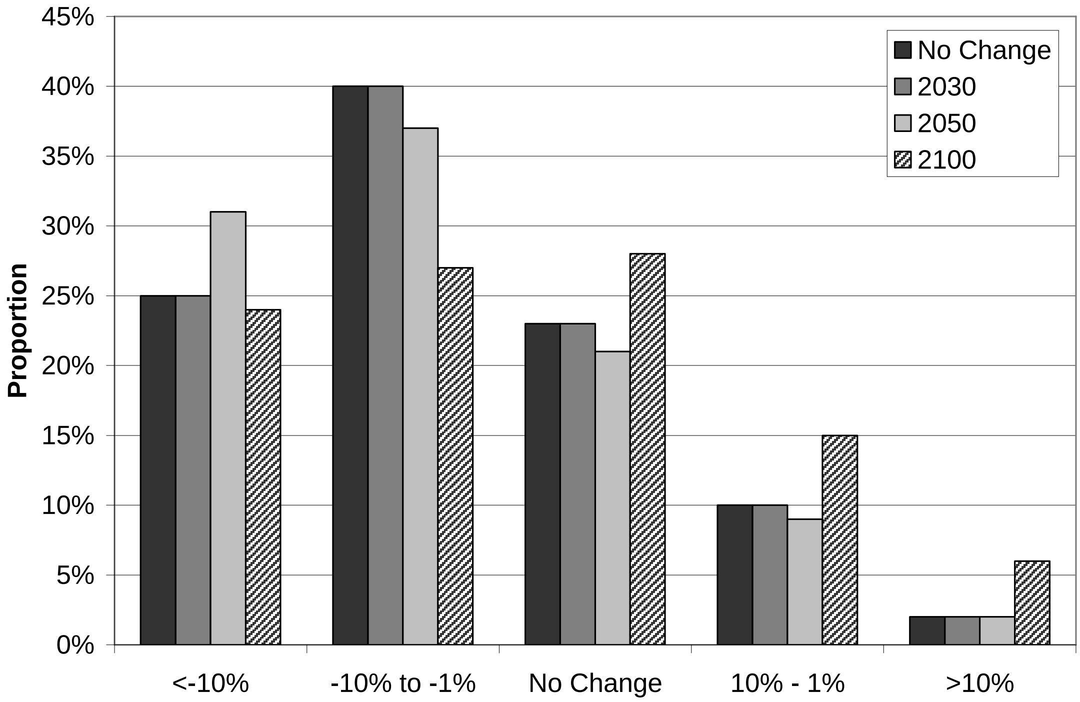

Figure 7. Impact of sea level rise options on seagrass

These figures show that while seagrasses can be expected to increase relative to the base case under the most extreme sea level rise option, saltmarsh and mangroves will likely decrease as the lagoon becomes less suitable habitat for these species. Also the model predicts a decrease in seagrass under the 2050 sea level rise scenario. This outcome is likely to be due to the conflicting influences of reduced total suspended sediments caused by increased flushing and greater lake depth. These factors influence light available in different directions leading to conflicted outcomes for seagrass growth. Given the paucity of data on seagrass growth and the interaction between these two factors these results should be treated extremely cautiously. However it is clear that there is potential for some species such as seagrass to increase or decrease in extent in the first instance as sea levels rise and then past a threshold for the opposite change to occur. Impacts on saltmarshes and mangroves are much more straightforward with increases in sea levels likely to substantially reduce the area of these habitats.

While impacts on ecological outcomes from the changes in sea level are mixed due to conflicting influences of water quality and depth on light and areas suitable for various species, the increased risk of flooding is likely to be a significant and relatively straightforward outcome of sea level rise. Impacts on flooding are demonstrated in more detail in Figure 8.

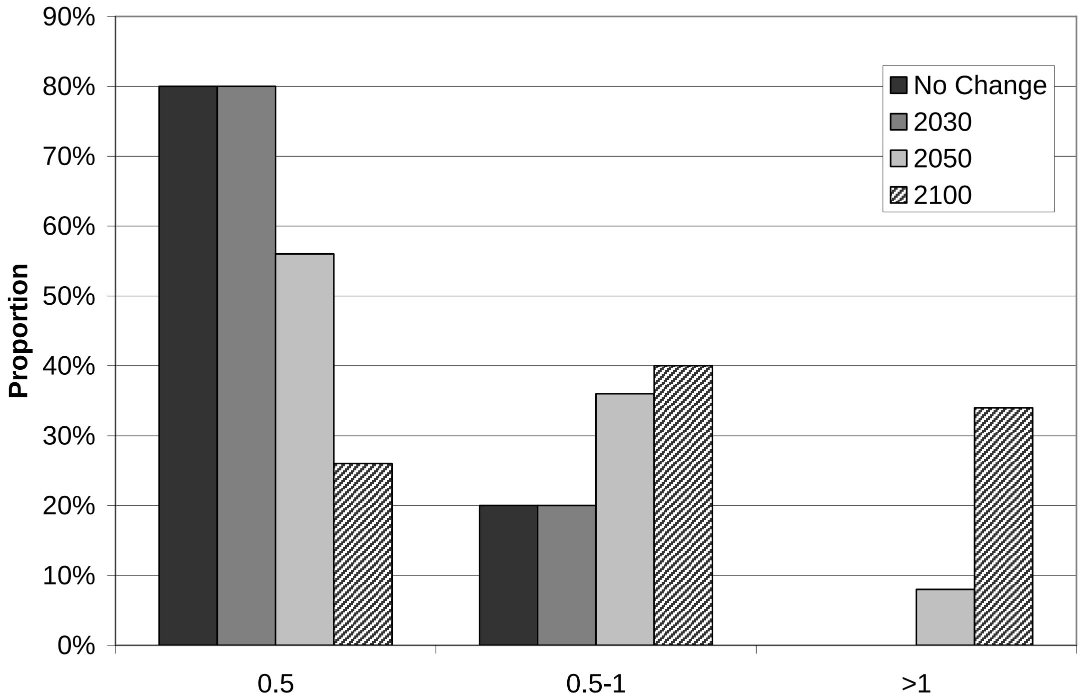

Figure 8. Impact of sea level rise options on flooding

This figure shows the effect of sea level rise on the average frequency of flood events in each year. Under current conditions the Urunga township experiences approximately one significant flood every two years. This is indicated by the probability density curve showing an 80% chance of less than 0.5 floods per year and 20% chance of 0.5 to 1 floods per year. Once sea levels rise to 2050 levels chances of experiencing more than one flood a year increase to 8% while at 2100 levels this probability becomes 34%. Chances of 0.5 to 1 flood are year also increase to 36% and 40% respectively. While the chance of flooding increases substantially the costs of flooding are relatively small, although they are an ongoing cost borne by residents and the Council. The costs of flooding under these different scenario options is summarised in Table 5. It should be noted that these are annualised costs, such that costs in any individual year might be greater or less than these but an average cost per year at this level can be expected.

Table 5. Approximate costs of flooding

	Approximate cost per year
No Change	$17,600
2030	$17,600
2050	$20,160
2100	$24,640

In summary the effects of sea level rise are quite complex. At 2030 levels, no impacts are expected given the states described by the CLAM model. At levels above this sea level rise is expected to increase lagoon depth and flushing. This generally decreases nutrient and sediment concentrations which in turn has mixed impacts for the lagoon ecology. Sea level rise is also expected to increase flooding of low lying areas and will lead to increased flood costs. These are not expected to be substantial in dollar terms, as a proportion of current costs they are relatively large (40% increase).

4.3 Management of the former antimony processing plant

Options for the management of the former antimony processing plant were run in the CLAM. Very isolated impacts were exposed by this run. This is likely to be due to the paucity of data on heavy metals in the lagoon and subsequent lack of knowledge about ecological and health effects of this contamination. As such very few impacts of heavy metal accumulation are present in the CLAM model. Only two impacts were shown by the model: the impact on lake heavy metals; and, the cost of public works. The CLAM shows a decrease in heavy metals resulting from either option for the management of the former processing plant. This qualitative impact does not discriminate between the two management options: Containment and Oxidation; and, Prevention Excavation and Relocation; because of a lack of data required to do so. Differences in costs were able to be shown with the second option likely to cost approximately $70,000 more than the first.

5 DISCUSSION OF THE RESULTS

This sustainability assessment report has provided a sample of results for management of the STP, the half tide training wall, and the former antimony processing plant 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 Urunga 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.

The results show that management of the half tide training wall and STP management act together to protect water quality and ecological health of the lagoon. A deep ocean outfall and removal of the half tide training wall provide the best outcomes, both together and in isolation. The cost differences between the different options are substantial however. While a deep ocean outfall may be preferable of the STP options for water quality outcomes this is also a very expensive option. Removal of the lower half tide training wall has a greater effect on water quality than any of the STP management options and is likely to lead to much greater ecological benefits even though it is the cheapest of the options presented. Human intervention in this system has the potential to significantly improve ecological and water quality outcomes of the lagoon.

In terms of the impacts of sea level rise due to climate change the results show that under sea level rise estimates of 2030 no impacts are expected on any node. However once sea level rises beyond this point to 2050 and 2100 levels then significant impacts can be expected. Primary impacts of sea level rise are to increase both lagoon depth and lagoon levels, by a larger amount for the higher sea level rise option of 2100 than for 2050. This is turn leads to increased flooding as well as increased flushing of the estuary. Very small reductions are experienced on water quality parameters at the 2050 level while at the 2100 impacts are likely to be a moderate decrease. Water quality related outcomes such as exceedance of ANZECC guidelines experience improvements while seagrasses, conservation values and tourism are shown to increase. It should be noted that this scenario considers sea level rise options only and does not consider the impacts of changes in rainfall, temperature and evaporation which would be likely to change at least some of these outcomes. The results show some indication of thresholds in the response of ecosystems, particularly in seagrasses. This means that while some changes may lead to an increase in the area or quality of a habitat for some level of change. Beyond this, substantial declines may be expected. Better understanding of these processes and their effects on the lake system are required. Local options to ameliorate some of these impacts should also be sought. Sea level rise is also likely to increase the frequency and magnitude of flood events, leading to increased costs from flooding.

Finally options for the management of the former antimony processing plant were considered. Results for this scenario were limited by the lack of data on the effects of management options and their consequences for heavy metal accumulation on human health and the aquatic environment. Data should be collected to allow these impacts to be better quantified.

The results shown here as well as the table of data quality provided in section 2.2 demonstrate some of the features of the data that has been used to underpin the Urunga CLAM. In most cases results have been based on a set of documented assumptions about the system behaviour which have been applied using a combination model to produce repeatable outputs or through the use of simple models which have been calibrated to existing data in some cases. It is most likely the case that improved modelling, particularly of lagoon flushing and its impacts on water quality and ecological outcomes, could help to better distinguish between different management actions. The CLAM is able to accept updates of such information over time as it becomes available. This should be considered in conjunction with other identified data collection requirements (see section 2.2).

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 Bellingen Shire Council, in particular Ian Turnbull, and the Bellingen Estuary Management Committee.

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.*

Appendix 1. Summary of Nodes in the Urunga CLAM tool

Node	Description	Output States	Units
Acid Sulfate Soil (ASS)	Change in the likelihood of oxidation of acid sulfate soils	Decreased risk, No change, Increased risk	
Aluminium Toxicity	This unit models the change in Aluminium toxicity	Decrease, No Change, Increase	
Algal Blooms	Change in the likelihood of Algal Blooms	Decrease, No Change, Increase	
ANZECC Guidelines	The output of the lake pathogen node is related to relevant ANZECC guidelines	no restriction, no aquaculture, no primary contact, no secondary contact	
Community awareness	The community awareness with respect to ecological functions of the lagoon and human impacts upon them	No change, Increase	
Conservation value	The value of Urunga Lagoon as a conservation refuge	Decrease, No Change, Increase	
Cost of public works	Estimate of dollars required to complete works implied by the selected scenarios (Total $ for works to be completed). Note it does not include maintenance costs. Currently does not attempt to account for any environmental gain following the works	>10000000	$
Cost of tourism	Estimate of dollar cost per year to government of providing infrastructure and advertising for tourism in Urunga	5% Decrease, No Change, 5% Increase	%
Disaster Cost	Estimate of dollars costs associated with flooding per year. Includes private and public works, loss of property and work	No Change, 1-50% increase, 50-100% increase	%
Disaster Management	Percentage change in disaster management costs per year due to flooding events	No change, 1- 50% increase, 50-100% increase	%
Faunal biodiversity	Change in the faunal biodiversity within Urunga Lagoon	Decrease, No Change, Increase	
Fish and invertebrate populations	Change in the populations of fish and invertebrates in Urunga Lagoon	large decrease, small decrease, no change, small increase, large increase	
Flooding	This unit models the change in frequency of significant flood events that affect properties within the Urunga Lagoon Catchment	<0.5, 0.5-1, >1	# events per year

Flushing	Percentage change in the lake flushing with the ocean	>60% increase, 60%-40% increase, 20%-40% increase, <20% increase	%
Input heavy metals	The risk of mobilization of heavy metals from the redundant antimony processing plant and it surrounds causing contamination of Urunga Lagoon	Decreased risk, No change	
Input pathogens	The concentration of faecal coliforms entering the lake from the catchment area as CFU/100ml	<50, 50-150, 150-500, 500-1000, >1000	CFU/100ml (CFU = colony forming units)
Input Total nitrogen	Inputs of total nitrogen to Urunga Lagoon. Current TN loads entering the lake are estimated to be 542-1816 kg/year.	<600, 600-1200, 1200-2400, >2400	kg/year
Input total phosphorous	Inputs of total phosphorus to Urunga Lagoon. Current TP loads entering the lake are estimated to be 156 – 353 kg/year	<100, 100-200, 200-300, 300-400, >400	kg/year
Input Total Suspended Solids	Inputs of total suspended solids to Urunga Lagoon. Current TSS loads entering the lake are estimated to be 11995 - 22620 kg/year	<8000, 8000-12000, 12000-16000, >16000	kg/year
Lagoon Depth	Average depth of Urunga Lagoon	<1, 1-1.25, 1.25-1.5, >1.5	m
Lagoon level	The level of the lake relative to current mean level	0-0.25, 0.25-0.5, >0.5	m
Mangroves	The area of mangroves within Urunga Lagoon	>10% decrease, 1-10% decrease, No change, 1-10% increase, >10% increase	%
pH	The average pH of the waters in Urunga Lagoon	7 – 7.5, 7.5 – 8, 8 – 8.5	
Public Works	Probability of any public work scenario	Work	
Ramsar Values	This variable models the ability of Urunga Lagoon to meet criteria for RAMSAR nomination	Decrease, No Change, Increase	
Recreational amenity	The value of Urunga Lagoon as a recreational resource	Decrease, No Change, Increase	
Recreational use	The change in recreational use of the Lagoon	Decrease, No change, Increase	
Salt marsh	The area of saltmarsh within Urunga Lagoon	>10% decrease, 1-10% decrease, No change, 1-10% increase, >10% increase	%
Sea grass	The area of seagrass within Urunga Lagoon	>10% decrease, 1-10% decrease, No change, 1-10% increase, >10% increase	%

Shoaling	The continued deposition of sediment within the lagoon	Decrease, No change, Increase	
Terrestrial habitat	The quality and variety of terrestrial habitat for native fauna	Decrease, No change, Increase	
Tourism	Change in tourism to Urunga	5% Decrease, No Change, 5% Increase	%
Tourist revenue	Estimate of dollar value per year to the Community as a result of tourism to Urunga	5% Decrease, No Change, 5% Increase	%
Visual amenity	This unit models the change in Visual Amenity	Decrease, No Change, Increase	
WQ Pathogen	The concentration of faecal coliforms in Urunga Lagoon	<14, 14-150, 150-1000, >1000	CFU/100ml (CFU = colony forming units)
WQ Total Nitrogen	Total nitrogen in Urunga Lagoon	<35, 35-55, 55-75, 75-95, >95	µg/L
WQ Total Phosphorous	Total phosphorus in Urunga Lagoon	<20, 20-30, 30-40, 40-50, >50	µg/L
WQ Total Suspended Solids	Total suspended sediment in Urunga Lagoon	<0.2, 0.2-0.3, 0.3-0.4, 0.4-0.5, <0.5	g m^{-3}

APPENDIX 2. ADDITIONAL SCENARIO GROUPS AVAILABLE IN THE CLAM TOOL

1. Manage Antimony Processing Plant
2. Manage Half Tide Training Wall
3. Manage Sewerage Treatment Plant
4. Manage Unreserved Crown Land
5. Recreational Facilities
6. Riparian Management
7. Sea Level Rise
8. Sediment Removal
9. Stormwater Management
10. Urban Development

Manage Unreserved Crown Land
There is a large area of unreserved crown land between the ocean beach and the eastern boundary of the lagoon. It is primarily made up of primary and secondary sand dune systems with patchy vegetation cover. This scenario explores the effect of revegetation programs to stabilise the dunes and improve the habitat value of the area.

Recreational Facilities
This scenario explores the effects of changed recreational amenities, which might include a new swimming platform in the old sea lido area, extensions on the raised timber walkway and an improved public education program.

Riparian Management
Riparian management efforts focussing on the southern boundary of Urunga Lagoon have successfully improved the quality of riparian vegetation in that area of the lagoon. This scenario explores an increase in riparian management efforts to include the patchier, weed infested areas of the western boundary.

Sediment Removal
There appears to be a net ingress of marine and land sourced sediment into Urunga Lagoon. The associated shoaling impacts the lagoon's ecological and hydraulic processes. This scenario option explores the effect of varied sediment removal regimes.

Stormwater Management
Stormwater from part of the Urunga Urban area flows into Urunga Lagoon without any filtering or sediment trapping. Stormwater control measures have the potential to improve water quality in Urunga Lagoon. This scenario explores upgrading the existing stormwater infrastructure for the urban area.

Urban Development
The South Urunga Development area has been subject to a number of development proposals. The most likely scenario is for the development of 250 lots towards the western boundary. This scenario explores the effects of a 250 lot development with a variety of control measures