Queens Lake Sustainability Assessment Report
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CONTENTS

EXECUTIVE SUMMARY

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

- Information on the extent and likely causes of any reduction in fish stocks in Queens Lake. This was an issue of concern with local community members although it has not been fully determined if there have been reductions in fish stocks in Queens Lake and, if so, the likely causes of these reductions;
- Local information on the impact of increased storm frequency and other aspects of climate change on localised flood frequency in Queens Lake;
- Information on the processes occurring in the lake, in particular flushing of the system and sediment movement and deposition. Any attempt to rectify this could include an assessment of Sea Level Rise impacts and the likely impact of dredging in Stingray Creek.

Three scenario groups were analysed:

- Residential development according to the Camden Hayden Urban Growth Strategy 2002 – 2022.
- Dredging of the delta within the lake at the upstream end of Stingray Creek, and
- Climate change including temperature, storm surge in combination with the impacts from sea level rise.

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

Residential Development

Four scenario options were explored within the residential development theme, which investigated the progressive increase in residential area within the lake catchment. The results showed that the changes in nutrient and sediment loads to the lake from urban areas would increase dramatically, despite the fact that there appears to be little impact upon the total lake water quality. This should raise concerns about the localised impacts upon important ecological species such as seagrass beds. It is recommended that further study be undertaken to consider the localised effects of residential development, given that seagrass is a protected species.

Dredging

The predicted impact upon the lake from dredging the delta near Stingray Creek indicates that dredging will remove the sediment believed to be obstructing boats, but will lead to a barely detectable increase in recreational boating. It will however create a large ecological cost through the loss of seagrass beds. Interestingly there is a greater likelihood of a reduction in seagrass, than there is a consequential increase in mangroves, which may have ecological impacts that are not currently represented within the CLAM.

Climate Change and Sea Level Rise

Climate change and sea level rise options were run in combination where the impact from sea level rise, and an increase in temperature and storm surges were explored. The model predictions indicated that small increases in sea level (2030 prediction) would have minimal impact upon the lake, but it would lead to a moderate increase in the lake water level. Given that the CLAM currently does not contain data on the localised flooding extent, the true

implications of this change cannot be gauged. With greater increases in sea level, as well as increases in the temperature and storm surges, the lake nutrient levels are predicted to decrease due to dilution. This appears to offset the impact from an increase in temperature as it relates to algal blooms, because there is not any dramatic change predicted in algae. With large changes in climate (2100 predictions) there are likely to be negative impacts upon the oyster fishery, so although this cannot be directly managed, it should be considered in future planning. However, the total economic impact upon the catchment may be offset by an increase in recreational boating and the corresponding tourism.

1 INTRODUCTION

This Sustainability Assessment report is based on results from the Coastal Lake Assessment and Management (CLAM) tool for Queens Lake. 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 Queens 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 development and use of CLAM models 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 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 QUEENS CLAM

2.1 Conceptual framework

The Queens Lake 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 algal blooms 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 and stormwater management. Definitions for all nodes in this conceptual framework are provided in Appendix 1.

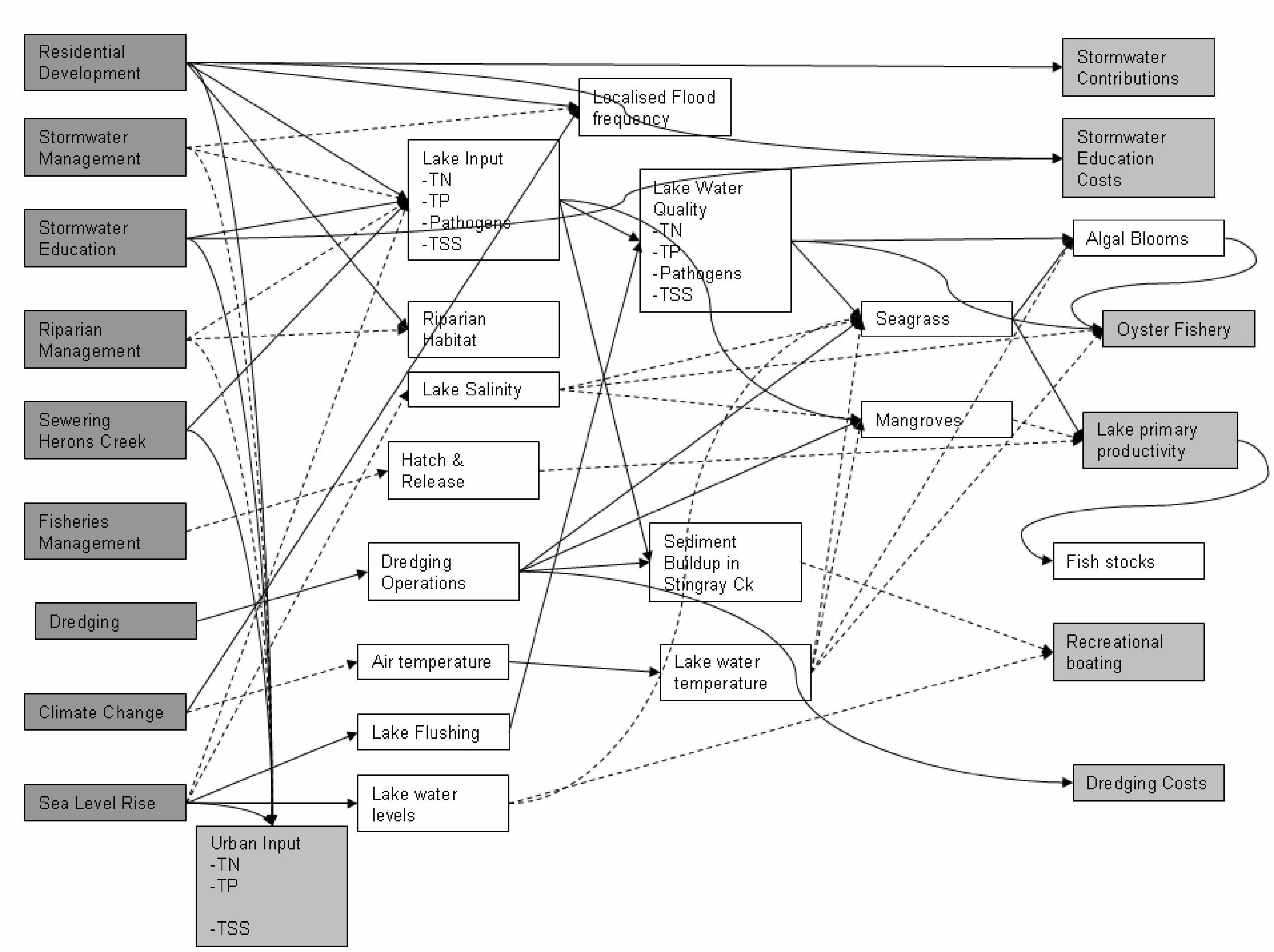

Figure 1. Queens Lake conceptual framework

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 Queens Lake is then given. This statement was provided by Tim Ruge who put together the data for the Queens CLAM.

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

Table 1. Data quality in the Queens CLAM

Node	Quality of Data	Reason	Suggested improvements
Air temperature	Good	Based on IPCC report for global temperature change with simple and conservative probability estimates	Expert review with application of climate change prediction models specific to the area or region.
Algal blooms	Average	Based on assumptions and iCAM combination model with some local data	Expert review and increased knowledge of the interactions between nutrients and algae or phytoplankton response in Queens or similar systems.
Dredging costs	Good	Based on costs estimates for similar activity	Could be improved with more detailed estimation of costs and local review.
Dredging operations	Excellent	Simple yes/no output states	Node definition could be strengthened with better scoping of the dredging program
Fish stocks	Incomplete	No data	Node included to stimulate further consideration. Expert and local input required to populate node.
Habitat	Very good	Based on GIS interpretation	Ground-truthing of GIS data interpretation and clarification of riparian revegetation.
Hatch and release	Incomplete	No data	Node included to stimulate further consideration. Expert and local input required to populate node.
Localised flood frequency	Incomplete	No data	Increased information on localised runoff would allow some data to be added to this variable.

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.
Lake pathogens	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.
Lake primary productivity	Incomplete	No data	Node included to stimulate further consideration. Expert and local input required to populate node.
Lake salilnity	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.
Lake TN	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.
Lake TP	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.
Lake TSS	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.
Lake water levels	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.
Lake water temperature	Average	Based on overseas studies applied to the local situation	Review from experts with application of climate change prediction models specific to the area / region.

Mangroves	Average	Based on literature reviewed assumptions and iCAM combination model (some local data)	Expert and local review. More mapping data on mangrove areas and species distribution coupled with water quality data and sediment analysis/accretion measurements.
Oyster fishery	Poor	Based on assumptions and iCAM combination model with some local data	Expert review and increased knowledge of the interactions between water quality and oyster production in Queens or similar systems.
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.
Recreational boating	Average	Based on assumptions and iCAM combination model with some local data	Expert and local review. Better quantitative understanding of sediment buildup.
Seagrass beds	Average	Based on literature reviewed assumptions and iCAM combination model with some local data	Expert review and increased knowledge of the interactions between water quality and seagrass beds in Queens or similar systems.
Sediment buildup in Stingray Creek	Average	Based on assumptions and iCAM combination model with some local data	Expert review and increased knowledge of the sediment movement and depositional dynamics.
Stormwater contributions	Good	Based on assumptions and local data	This node could be improved with review from Council planners and consideration of future stormwater funding policies.
Stormwater education costs	Good	Based on assumptions and local data	This node could be improved with review from Council planners and consideration of future stormwater funding policies.

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.
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.
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.
Urban 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.
Urban 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..
Urban 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..

Excellent: Models based on local data, supported assumptions, expert review and calibrated/verified with measured (local) data. For direct changes in measured areas where derived from ground-truthed GIS interpretation. Simple yes/no output models.
Very good: Models based on local data, supported assumptions, expert review and calibrated/verified with measured (local) data which may be limited in extent
Good: Models supported by expert review or local data. May be calibrated/verified with measured (local) data which may be limited in extent or show some areas for improvement of model fit.
Average: Uncalibrated models or based on assumptions with some supporting local data or expert review.
Poor: Based on untested assumptions with little or no supporting local data or expert review.

Priority data collection areas identified by Tim Ruge are:

- Information on the extent and likely causes of any reduction in fish stocks in Queens Lake. This was an issue of concern with local community members although it has not been fully determined if there have been reductions in fish stocks in Queens Lake and, if so, the likely causes of these reductions;
- Local information on the impact of increased storm frequency and other aspects of climate change on localised flood frequency in Queens Lake;
- Information on the processes occurring in the lake, in particular flushing of the system and sediment movement and deposition. Any attempt to rectify this could include an assessment of Sea Level Rise impacts and the likely impact of dredging in Stingray Creek.

3 SCENARIOS

In order to develop this Sustainability Assessment analysis a relatively small subgroup of scenarios were selected from the 4608 available in the Queens CLAM. It was decided to focus on the following scenarios:

- Residential development according to the Camden Haven Urban Growth Strategy 2002 – 2022 (Hastings Council, 2003).
- Dredging of the delta within the lake at the upstream end of Stingray Creek, and
- Climate change including temperature, storm surge in combination with the impacts from sea level rise.

These sets of scenarios are considered in isolation to each other. The impacts that are 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 Residential Development

This scenario assesses urban development identified in the Camden Haven Urban Growth Strategy 2002 – 2022 and other areas under political pressure to develop. This scenario assesses existing development and three options of future development:

1. No change (existing development)
2. residential development of areas zoned “Residential” which are currently undeveloped;
3. residential development of areas zoned “Urban Investigation” in addition to the above option; and
4. residential development of areas additional to the above which are currently under political pressure for development.

Option 2 assumes approximately 70 hectares (ha) of land zoned “Residential” will be developed. This area is currently bushland (65ha) and unimproved pasture (5ha) and is mainly located in the Lakewood area. Some areas zoned “Residential” are considered unsuitable for development because of severe constraints such as vegetation, drainage lines, etc and have not been included.

Option 3 assumes approximately 114ha of land zoned “Urban Investigation” will be developed. This area is currently bushland (7ha) and unimproved pasture (107ha) and is mainly located west of the Lakewood area. It was assumed that approximately 40% of the total area zoned “Urban Investigation” could not be developed due to severe constraints such as vegetation.

Option 4 considers lands not identified for development in the strategy which are currently under political pressure to develop due to demand and commercial viability. Council and community indicated that this pressure for development is likely to increase in the future. It is assumed that approximately 70ha of land zoned rural will be developed. This area is located to the east of Queens Lake and is based on identification of ‘cleared’ unimproved pasture areas from aerial photograph mapping.

Scenario Development

This scenario was initially identified by GeoLINK (Tim Ruge) to be one of the main issues for the catchment. Community concerns raised during initial discussions with Residents Action Network (RAN) indicated that development was a concern. Council (Matt Rogers) agreed to include the scenario in the CLAM. Option No.4 for this scenario arose from discussions with community (RAN) and Council.

This scenario addresses the management of urban development identified in the Camden Haven Urban Growth Strategy 2002 – 2022 and this scenario option 4, the development area will need to be approximated in consultation with Council with consideration of environmental constraints. Likewise for scenario options No. 2 and 3 there will need to be an estimate of the impact of environmental constraints on the extent of development within the identified areas.

3.2 Dredging

This scenario assesses the impact of dredging the delta within Queens Lake at the upstream end of Stingray Creek. This option is based on recommended strategies in the Camden Haven Estuary Management Plan, Strategy Implementation Schedule (Recommended Strategy No. 22).

The Camden Haven Estuary Management Plan indicated a cost of $350,000 to undertake this program which would include the following tasks:

1. Undertake substantial study and prepare Review of Environmental Factors.
2. Assess methods for dredging and logistics of undertaking work, including dredge spoil disposal sites.
3. Prepare design for dredging footprint and associated documentation for agency approvals.
4. Undertake dredging of the pilot channel.

The ongoing annual cost of the dredging is estimated at $200,000.

Scenario Development

This scenario was initially identified by GeoLINK (Tim Ruge) and is recognized as a strategy in the Estuary Management Plan. Council (Matt Rogers) indicated that it wasn't a major issue.

3.3 Climate Change and Sea Level Rise

Climate Change

This scenario aims to assess the impacts of predicted changes in weather patterns due to global warming. The scenario aims to assess the impact of predictions for the year 2050 and 2100 on increased air temperatures and increased storm frequency.

The impact of warmer air temperatures has been assessed based on 2001 predictions by the Intergovernmental Panel on Climate Change (IPCC) – *Special Report on Emissions Scenarios* (SRES). The predictions for global temperature change relative to 1990 are shown in the table below.

Year	Global Temperature Change (°C)
1990	0
2000	0.2
2050	0.8-2.6
2100	1.4-5.8

In the current version on the Queens Lake CLAM, the impact of increased storm frequency has not been assessed due to lack of information on predictions specific to the area. This has been identified as a potentially important scenario and should be updated in the CLAM tool once this information is available.

The options considered in this scenario are:

- No Change
- 2050
- 2100

Scenario Development

This scenario was initially selected by GeoLINK (Tim Ruge) in response to initial community consultation. Council (Matt Rogers) agreed that the scenario could be included in the CLAM tool.

Sea Level Rise
The sealevel 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 predicted sealevel 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

The options are:

No change
Sea level rise prediction for 2030
Sea level rise prediction for 2050
Sea level rise prediction for 2100

Scenario Development
This scenario was initially selected by GeoLINK (Tim Ruge). Council (Matt Rogers) agreed that the scenario could be included in the CLAM tool.

4 RESULTS FROM SCENARIO RUNS

4.1 Residential Development

Residential Development options were run in isolation and their impacts considered for all nodes. Table 2 summarises the impacts of Residential Development on all nodes for which there was an impact. Unimpacted nodes were: Lake pathogens; Lake TP; Algae; Localised Flood Frequency; Dredging Operations; Air temperature; Lake water levels; Sediment Buildup in Stingray Creek; Fish Stocks; Recreational Boating; Oyster Fishery; Lake Primary Productivity; Dredging Costs; Lake Flushing; Lake Salinity; Lake water temperature; Hatch and Release; and Stormwater Education Costs.

Table 2. Summary of impacts of residential development

	Develop residential zones	Develop urban investment zones	Develop 70ha of rural zone
Lake TSS	Very small increase	No impact	No impact
Lake TN	Very small increase	Very small increase	Very small increase
TN Input	Very small increase	Very small increase	Very small increase
TSS Input	Very small increase	Very small increase	Very small increase
TP Input	Very small increase	Very small increase	Very small increase
Pathogen Input	Very small increase	Very small increase	Very small increase
Habitat	No impact	Decrease	No impact
Seagrass Beds	Very small decrease	Very small decrease	Very small decrease
Mangroves	Very small increase	Very small increase	Very small increase
Urban TN Input	Moderate increase	Moderate increase	Moderate increase
Urban TSS Input	Moderate increase	Moderate to large increase	Moderate increase
Urban TP Input	Large increase	Large increase	Large increase
Stormwater Contributions	Residential zone costs	Urban investment costs	Political zone costs

This table shows that the impact of residential development on Queens Lake as a whole might appear to be minimal with changes in total nitrogen, phosphorus, suspended sediment and pathogens experiencing no more than a very small increase. This leads to a prediction of a very small decrease in seagrass beds (Figure 2) and a very small increase in mangroves. However, localised impacts could be greater. When isolating the nutrient and sediment input into the lake from urban areas only, there is a marked increase in total nitrogen (TN),

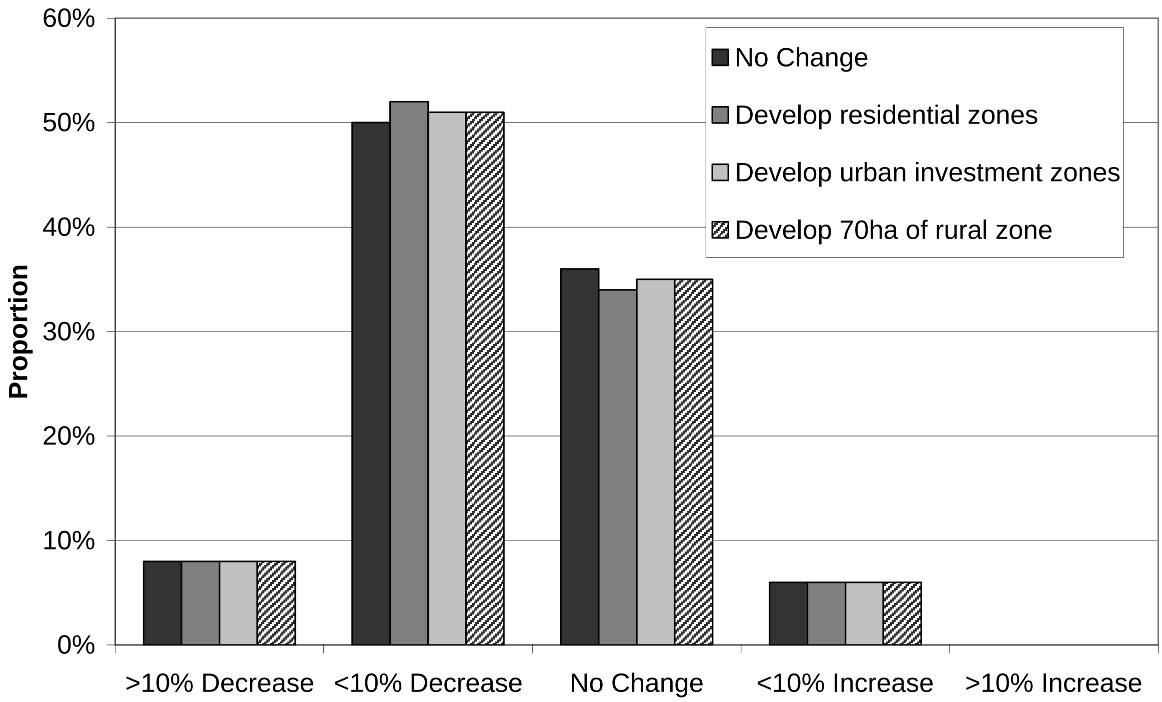

Figure 2. Impact of residential development on seagrass beds

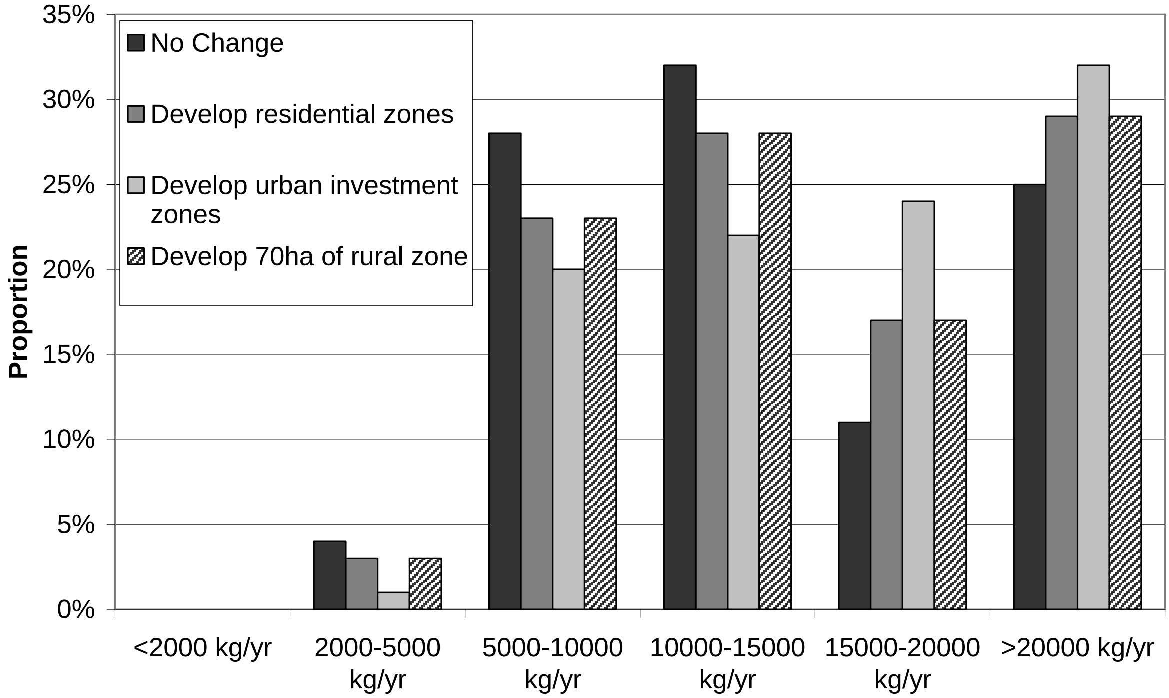

Figure 3. Impact of residential development on urban total suspended sediment Input

phosphorus (TP) and suspended sediment (TSS) in all residential development scenarios, compared to the current condition. Figure 3 shows this trend for TSS but it should be noted that the third residential development option of developing 70ha of rural zone is likely to have less of an impact upon the urban TSS than development of the residential zones and urban investment zones. This is counter intuitive because by definition, each residential development scenario is in addition to the scenario before (Section 3.1). Given the current landuse of the area mapped as the 70ha rural zone, and the expected TSS loads from the different land uses, the likely TSS load should at least remain the same if the area under urban development was to increase. This should be investigated more closely.

The BDN framework given in Figure 1 shows that the urban water quality inputs are not linked into any other variables in the framework. However, depending on the location of the seagrass beds compared to the urban scenario locations, the moderate to large changes in local nutrient and sediment load to the lake could have a marked negative impact upon the nearby seagrass beds. This has large implications given that seagrasses are a protected species in NSW, and highlights a substantial risk in making management decisions which might impact upon this protected specie. Further investigation at a smaller scale is recommended.

4.2 Dredging

Dredging options were run in isolation and their impacts considered for all nodes. Table 3 summarises the impacts of Dredging on all nodes for which there was an impact. Unimpacted nodes were: Lake TSS; Lake TN; Fish Stocks; Lake pathogens; TN Input; Algae; Pathogen Input; Localised Flood Frequency; Lake TP; TSS Input; TP Input; Habitat; Air temperature; Lake water levels; Recreational Boating; Oyster Fishery; Lake Primary Productivity; Lake Flushing; Lake Salinity; Lake water temperature; Hatch and Release; Urban TN Input; Urban TSS Input; Urban TP Input; Stormwater Education Costs; and Stormwater Contributions.

Table 3. Summary of impacts of sea level rise

	Dredge
Dredging Operations	Dredge
Dredging Costs	Dredging costs
Sediment Buildup in Stingray Creek	Moderate decrease
Seagrass Beds	Moderate decrease
Mangroves	Small increase

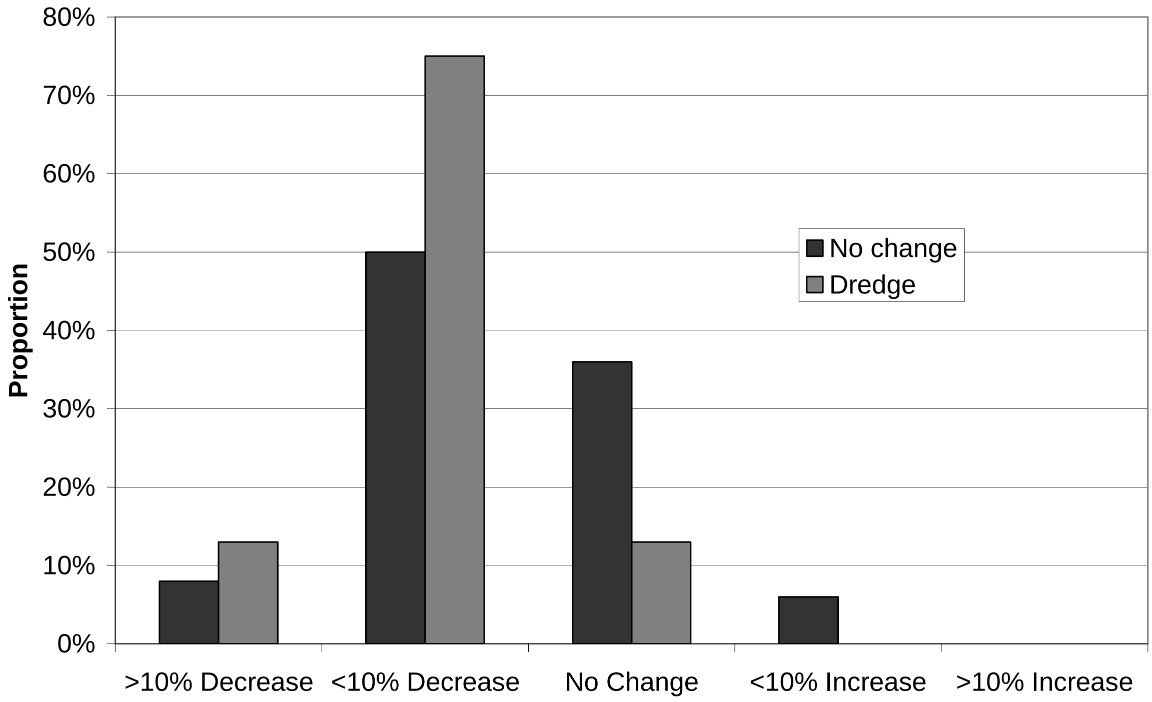

Figure 4. Impact of dredging on seagrass beds

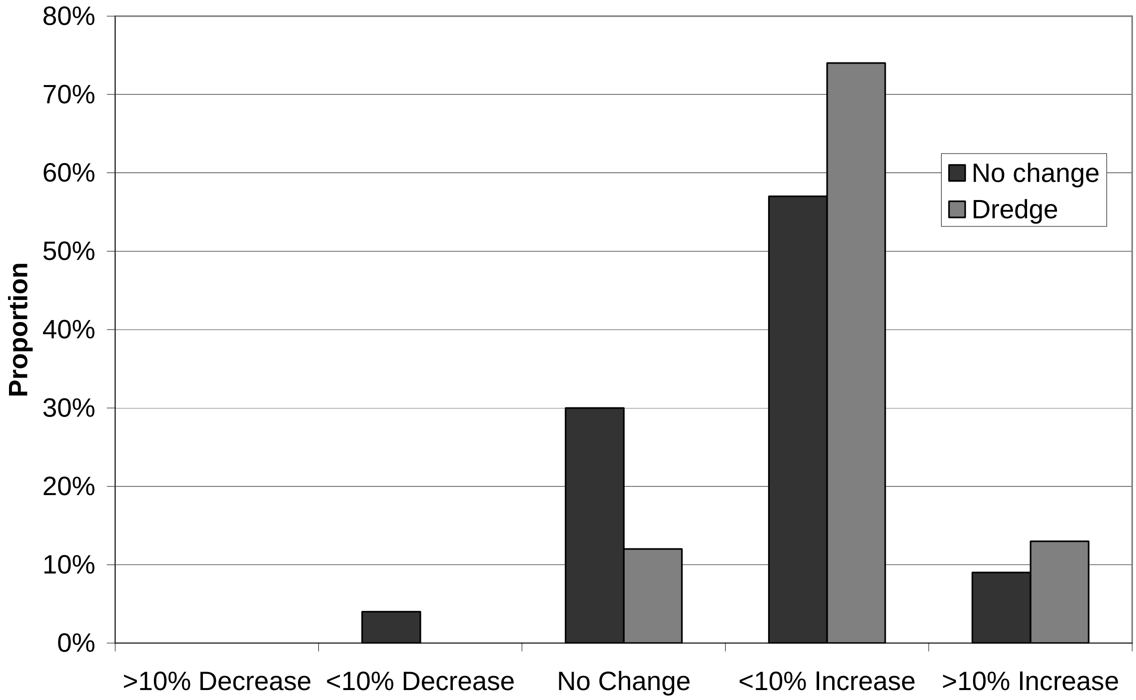

Figure 5. Impact of dredging on mangroves

This table shows that dredging the delta near Stingray Creek is likely to decrease the sediment build-up, as would be expected, but has no impact upon recreational boating. However, there are ecological impacts, evident through the moderate decrease in seagrass beds. Figure 4 shows that dredging increases the likelihood of less than 10% decrease in seagrass by 25%, and the likelihood of a greater than 10% increase by 5%. The corresponding increase in mangroves (Figure 5) is 17% for less than 10% increase and 4% for greater than 10% increase. This indicates that the potential loss of seagrass is greater than the potential gain in mangroves, which could equate to a loss in aquatic habitat and primary productivity. Unfortunately the lake primary productivity and fish stock variables shown to be linked to seagrass and mangroves in the framework presented in Figure 1, has not yet been populated with data due to a lack of information. This information would be crucial in order to trade-off the full extent of the impact from dredging in Queens Lake.

4.3 Climate Change and Sea Level Rise

Climate change and sea level rise options were run in combination where the impact from the following scenarios upon all nodes was considered:

- sea level rise in 2030 without other climate change impacts,
- sea level rise in 2050 with an increase in temperature and storm surges, and
- sea level rise in 2100 with an increase in temperature and storm surges.

Table 4 summarises the impacts of climate change and sea level rise on all nodes for which there was an impact. Unimpacted nodes were: Lake pathogens; TSS Input; Pathogen Input; Habitat; Localised Flood Frequency; Dredging Operations; Sediment; Buildup in Stingray Creek; Mangroves; Fish Stocks; Lake Primary Productivity; Dredging Costs; Hatch and Release; Urban TN Input; Urban TSS Input; Urban TP Input; Stormwater Education Costs; Stormwater Contributions; TN Input and Algae.

Table 4. Summary of impacts of climate change (increase in temperature and storm surges) and sea level rise (SLR)

	2030 SLR, no other climate change	2050 SLR and climate impact	2100 SLR and climate impact
Lake TSS	No impact	Very small decrease	Small decrease
Lake TN	No impact	Very small decrease	Small to moderate decrease
Lake TP	No impact	Moderate decrease	Large decrease
TP Input	No impact	Very small decrease	Very small decrease
Air temperature	No impact	Moderate increase	Large increase
Lake water levels	Moderate increase	Large increase	Very large increase
Seagrass Beds	Very small decrease	Small decrease	Moderate decrease
Recreational Boating	Small to moderate increase	Moderate increase	Large increase
Oyster Fishery	No impact	Small decrease	Moderate decrease
Lake Flushing	No impact	Moderate decrease	Large decrease
Lake Salinity	No impact	Moderate increase	Large increase
Lake water temperature	No impact	Moderate increase	Large increase

Table 4 indicates that with a rise in sea level to the height predicted for 2030 there is no impact upon water quality or lake flushing, but a moderate increase in lake water level is expected. In the absence of data for the localised flooding extent the impact on local infrastructure can not be gauged. The change in water levels in turn leads to a very small decrease in seagrass beds, due to the decrease in light infiltration through the deeper waters, and a small to moderate increase in recreational boating, possibly due to the greater area of water accessible for recreation. With greater change in the sea level and climate (2050 and 2100 predictions) the lake nutrient and suspended sediment concentrations decrease, due to the dilution of the inputs within the now larger water body. This is predicted to offset the impact of increased lake water temperature with regards to algal blooms, as there is no impact predicted under these scenarios.

Lake salinity is predicted to increase, largely from an influx of sea water into the lake (shown through the increase in lake water levels). The uncertainty around the predictions in lake salinity can be seen in Figure 6, particularly for the 2100 scenarios where the probability distribution is spread across all but one possible class. The uncertainty increases with the length of prediction into the future due to the uncertainty associated with climate change predictions.

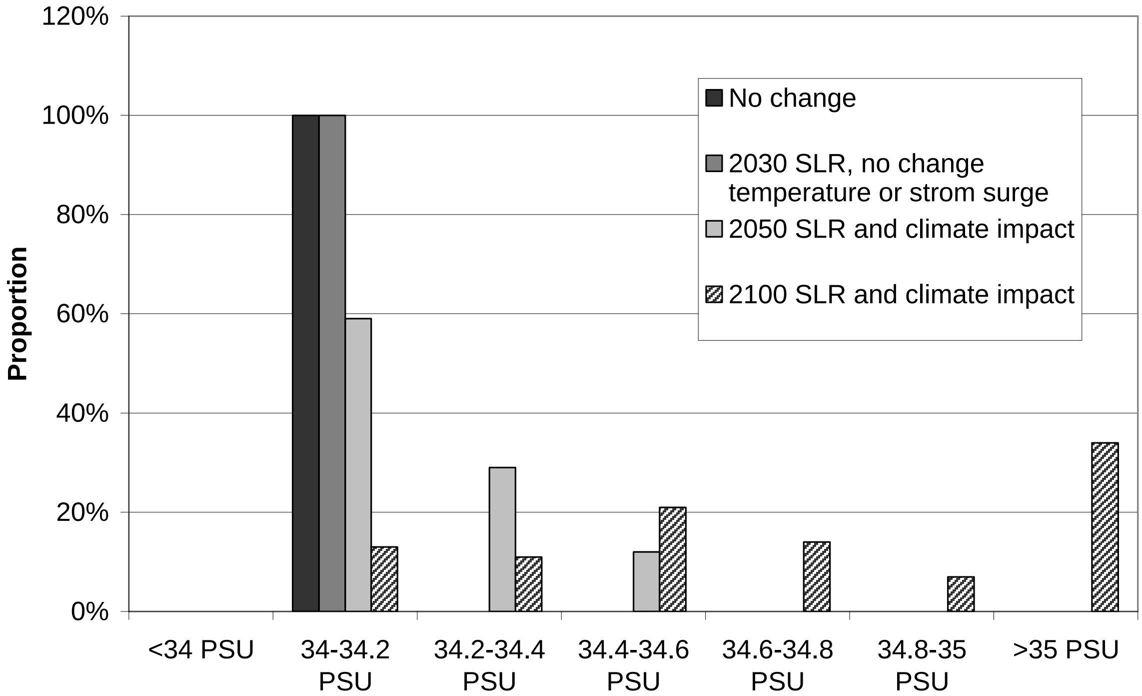

Figure 6. Impact of climate change and sea level rise on lake salinity

The impacts of lake water quality and temperature, as it changes under climate change and sea level rise, impacts negatively upon the oyster fishery (Figure 7). The oyster fishery is increasingly likely to decrease due to the increase in lake salinity. However the economic impact might be at least partially offset by the corresponding increase in recreational boating (Figure 8) due to the increase in the navigational opportunities from the increase in lake water level. It is difficult to make more than a qualitative trade-off between these two variables without additional economic values to help describe the changes. As such, the likelihood of a decrease in the oyster fishery increases by about 25%, while the likelihood of an increase in navigation for recreational boating increases by 50%. Seeing that climate change and sea level rise is essentially beyond the control of the catchment managers at Queens Lake, this is a trade-off that may be unavoidable although forward planning could be made to pre-empt the impact upon the oyster fishery so as to not lead to serious negative economic or social impacts.

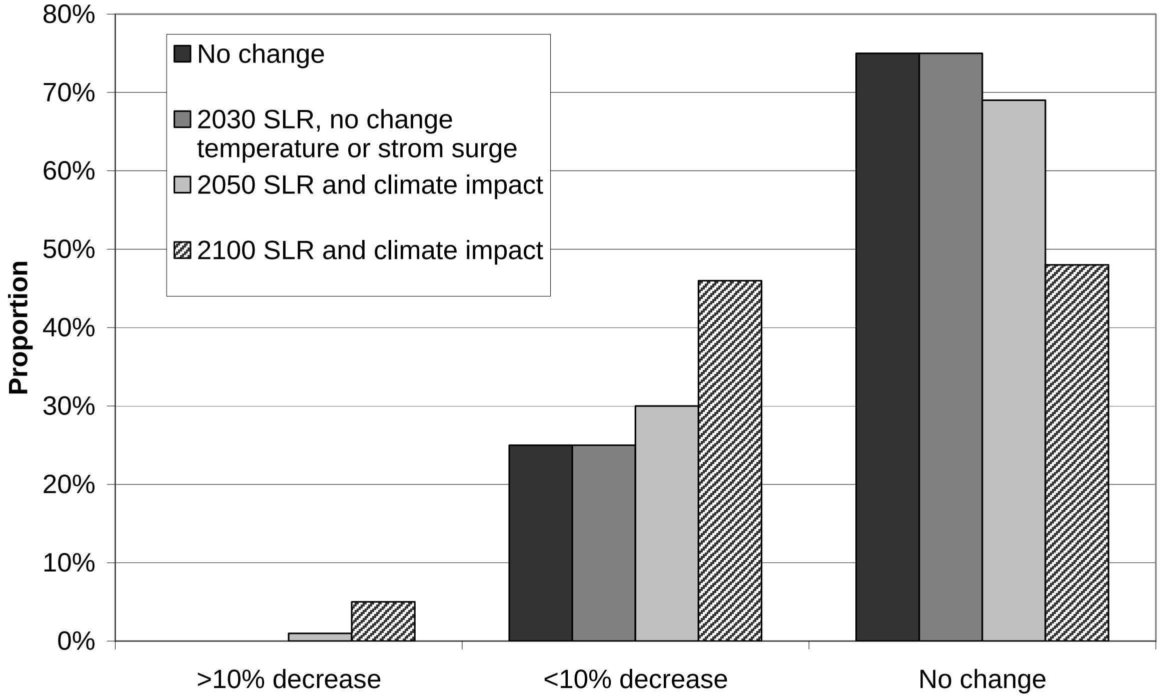

Figure 7. Impact of climate change and sea level rise on the oyster fishery

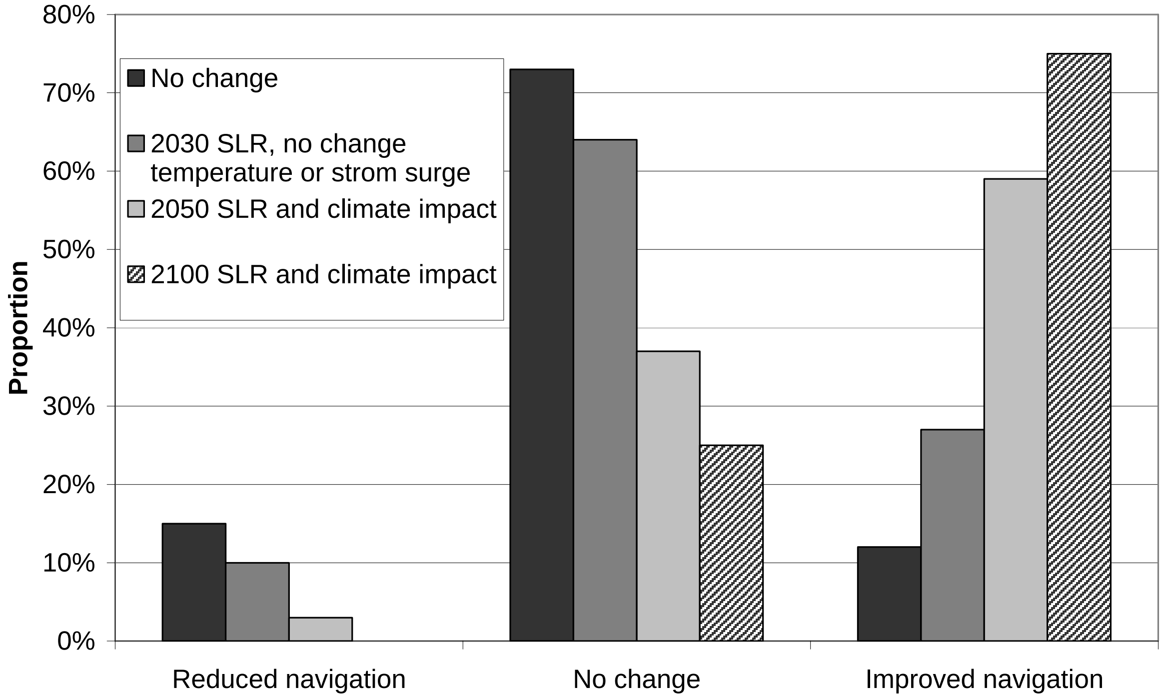

Figure 8. Impact of climate change and sea level rise on the recreational boating

5 DISCUSSION OF THE RESULTS

This Sustainability Assessment report has provided a sample of results for management residential development, and dredging within Queens Lake as well as of the impacts of climate change and sea level rise. These options are a small subset of the total number of scenarios which can be considered by the Queens CLAM and as such do not provide conclusive evidence of the 'best' management options available.

Analysis of the residential development scenarios showed that localised effects on the water quality in Queens Lake could be significant, which could lead to significant ecological impacts near outflow areas. Dredging near Stingray Creek was shown to remove the delta forming but the changes to boating recreation was minimal compared to the large negative impacts upon seagrass beds. Additional information on the localised flooding extent is required in order to judge the impact of climate change for the year 2030 but the predictions for 2100 show that they oyster fishery is likely to suffer. This may be offset by an increase in recreational boating. Although these changes can not be directly controlled by local managers, forward planning could assist in minimising the economic and social impacts for climate change.

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 Queens CLAM. In some cases variables do not contain data because there was not any available. These variables are focused around the aquatic populations and include Fish stocks, Hatch and release, and Lake primary productivity. In addition the Oyster fishery is also considered to have a poor data quality. 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

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APPENDIX 1. SUMMARY OF NODES IN THE QUEENS LAGOON CLAM TOOL

Node	Description	Output States	Units
Air temperature	Increase in average air temperature resulting from climate change	0 to 0.8°C increase, 0.8 to 1.6°C increase, 1.6 to 2.4°C increase, 2.4 to 3.2°C increase, 3.2 to 4.0°C increase, 4.0 to 4.8°C increase, 4.8 to 5.6°C increase, > 5.6°C increase	°C
Algal blooms	Change in the occurrence of algal blooms in Queens Lake	>10% decrease, <10% decrease, No change, <10% increase, >10% increase	%
Dredging costs	Annual Council costs for dredging Stingray Creek		$/year
Dredging operations	Implementing a dredging program	No Dredging, Dredging	
Fish stocks	Changes in fish stock numbers		
Habitat	The area of bushland / wetlands / riparian habitat that will be created or lost (expressed as a percentage of current habitat area in the total catchment)	Minor increase (<0.1% or < 10ha), decrease of 0 to 0.5% (or 0 to 50 ha decrease), decrease of 0.5 to 1.0% (or 50 to 100 ha decrease), decrease > 1.0% (or > 100 ha decrease)	%
Hatch and release	A replenishment of prawn numbers in Queens Lake via implementation of a large scale hatch and release program		
Lake flushing	Percentage change in the lake flushing with the ocean	<10% Decrease, 10 - 5% Decrease, 5 - 0% Decrease, No Change	%
Lake pathogens	The concentration of faecal coliforms in Queens Lake as CFU/100ml	<14, 14-100, 100-300, 30-1000, >1000	cfu/100ml (CFU = colony forming units)
Lake primary productivity	Primary Productivity - a measurement of plant production that is the start of the food chain. Much primary productivity in marine or aquatic systems is made up of phytoplankton, which are tiny one-celled algae that float freely in the water		
Lake salinity	Lake salinity, represented as a range in concentration (practical salinity units)	<34, 34-34.2, 34.2-34.4, 34.4-34.6, 34.6-34.8, 34.8-35, >35	
Lake TN	Total nitrogen in Queens Lake	<220, 220-270, 270-320, 320-370, >370	µg/L
Lake TP	Total phosphorus in Queens Lake	<9, 9-9.3, 9.3-9.6, 9.6-9.9, >9.9	µg/L

Lake TSS	Total suspended sediment in Queens Lake	<5.3, 5.3-5.8, 5.8-6.3, 6.3-6.8, >6.8	g/m^3
Lake water depth	Change in the lake water depth	<1.2, 1.2-1.3, 1.3-1.4, 1.3-1.4	m
Lake water temperature	Increase in average water temperature of Queens Lake resulting from climate change	No change, <10% increase, >10% increase	%
Localised flood frequency	Increased frequency of flooding events resulting from climate change		
Mangroves	Change in the area of mangroves on the foreshores of Queens Lake and Stingray Creek	>10% decrease, <10% decrease, No change, <10% increase, >10% increase	%
Oyster fishery	Impact on Oyster Fishery both in terms of oyster production and oyster sales	>10% decrease, <10% decrease, No change	%
Pathogen input	The concentration of faecal coliforms entering the lake from the catchment area as CFU/100ml	<14, 14-100, 100-300, 300-1000, >1000	cfu/100ml (CFU = colony forming units)
Recreational boating	Impacts on navigation for recreational boating in Queens Lake	Reduced navigation, No change, Improved navigation	
Seagrass beds	Change in the area of seagrass in Queens Lake	>10% decrease, <10% decrease, No change, <10% increase, >10% increase	%
Sediment buildup in Stingray Creek	Build up of sediment levels in Stingray Creek	>10% decrease, <10% decrease, No change, <10% increase, >10% increase	%
Stormwater contributions	Council costs for annual stormwater education funding for Queens Lake catchment		$/year
Stormwater education costs	Council costs for annual stormwater education funding for Queens Lake catchment		$/year
TN input	Inputs of total nitrogen to Queens Lake. Current TN loads entering the lake are estimated to be 8879 kg/year	<4000, 4000-6000, 6000-8000, 8000-10000, 10000-12000, >12000	kg/year
TP input	Inputs of total phosphorus to Queens Lake. Current TP loads entering the lake are estimated to be 1683 kg/year	<4000, 4000-6000, 6000-8000, 8000-10000, 10000-12000, >12000	kg/year
TSS input	Inputs of total phosphorus (kg/year) to Queens Lake. Current TP loads entering the lake are estimated to be 159275 kg/year	<4000, 4000-6000, 6000-8000, 8000-10000, 10000-12000, >12000	kg/year
Urban TN input	Inputs of total nitrogen to Queens Lake sourced from urban lands	<400, 400-800, 800-1200, 1200-1600, 1600-2000, >2000	kg/year

Urban TP input	Inputs of total phosphorus to Queens Lake sourced from urban lands	50, 50-100, 100-150, 150-200, 200-250, >250	kg/year
Urban TSS input	Inputs of total suspended sediment to Queens Lake sourced from urban lands	<2000, 2000-5000, 5000-10000, 10000-15000, 15000-20000, >20000	kg/year

APPENDIX 2. ADDITIONAL SCENARIO GROUPS AVAILABLE IN THE CLAM TOOL

1. Stormwater Management
2. Riparian Management
3. Sewering Herons Creek
4. Stormwater Education
5. Fisheries Management

Stormwater Management

This scenario assesses the impact of current stormwater management strategies that are in initial stages of investigation and implementation by Council. West Haven is one area that Council is initially focussing on. The scenario relates to current strategies in initial stages of investigation / implementation. More specifically, they consider the development of Catchment Action Plans and Water Sensitive Urban Design (WSUD) Development Control Plans (DCP's) for residential areas. These initiatives will ensure stormwater improvements proposed conform to current trends for WSUD and have due regard to ecological sustainable development (ESD) principles.

Riparian Management

This scenario assesses the impact of revegetation of waterways and lake foreshores. It scenario is based on strategies outlined in Council's Camden Haven Estuary Management Plan. The strategy outlined in the plan involves retaining / reinstating 30m wide buffer strip along lake edge. The option assessed in this model investigates reinstating riparian vegetation along areas currently devoid of vegetation. These areas have been identified through investigation of aerial photograph mapping. Assessment of areas devoid of riparian vegetation identified only areas along Bobs Creek where there was a distinct lack of riparian vegetation based on aerial photograph mapping. No significant changes to riparian areas were assumed for Herons Creek and Queens Lake foreshores.

Sewering Herons Creek

This scenario assesses the likely scenario of sewering Herons Creek township which has identified failing septic systems that are potentially impacting on water quality in Herons Creek, a major tributary of Queens Lake. Sewering of the town will remove this nutrient input to the lake system which is accounted for in the pollutant input nodes of the CLAM model.

Stormwater Education

This scenario assesses the impact of a stormwater education program on pollutant loads to the lake.

Fisheries Management

This scenario addresses concerns of reductions in fish stocks in Queens Lake. It has been included based on issues and initiatives raised by community input to the development of the model. It is currently only included as a skeleton to stimulate further consideration of the impact of potential mitigation measures on fisheries and primary productivity of the lake. Following further consultation data can be added to the model to make this scenario functional.

It is not fully determined if there has been reductions in fish stocks in Queens Lake. Studies indicating potential reductions suggest possible causes being attributed to fishing, natural cycles of drought and flood and consequent changes in water quality (Camden Haven Estuary Processes Study, 1999). This scenario includes initiatives for re-stocking of the lake re-establish aquatic bio-systems to address nutrient enrichment of lake and imbalances caused by fishing and development impacts.