Deep Creek Sustainability Assessment Report

December 2006

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EXECUTIVE SUMMARY

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

- Information on the processes occurring in the estuary, in particular flushing of the system and understanding of the spatial nature of flushing in the estuary (which parts are well flushed, where are the connections within the estuary, are parts of the estuary isolated or more likely to be impacted on by water quality changes given differences in flushing regime);
- Data and modelling of freshwater inflows to the estuary;
- Better topographic data on the estuary and foreshore areas. This data is needed at a fine scale to allow estuary processes to be understood and to give a better idea of flooding impacts.

This report examines the impact of entrance management, riparian land management, urban development and management of the STP. 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.

Entrance opening
Changes to entrance opening are likely to have small to moderate impacts on estuary water quality parameters. The greatest water quality impact is a moderate decrease in estuary TN when both options 2 and 3 and an ANZECC trigger are used. These relatively small water quality impacts generate ecological impacts which are also small, with most parameters, such as wetlands, saltmarsh, seagrass beds and mangroves experiencing a very small increase. The greatest impact of entrance opening is on flooding of agricultural and residential lands and on recreational fishing which experiences a moderate increase. Agricultural lands experience a moderate increase in flooding under the first two options, and a small increase under ANZECC trigger levels. Residential flooding impacts are more complex with a moderate increase for a return to natural opening, and moderate to moderate to large decreases for other options.

Riparian Management
For riparian management it was shown that all three options: Buffers for new developments or subdivisions; Buffer incentives offered; and, Agricultural buffers required; lead to improvements in water quality and ecological outcomes. The best ecological and sedimentation outcomes are generally experienced under buffer incentives.

Urban development
Urban development has negative impacts on some water quality and ecological outcomes, particularly in terms of increasing estuary TSS and reducing seagrass beds, regardless of the type of development or constraints used. Two different development areas were considered – Cow/Boggy Creek and south west Valla. Scenarios for these areas showed that constraining development in SW Valla does lead to improvements in outcomes relative to development on all 1(d) areas. Development of both areas is also seen to lead to cumulative impacts that are worse than either in isolation.

Urban development with STP management

STP management is likely to reduce the input of pollutants such as pathogens and TN to the estuary but these are not large enough to have a noticeable effect on estuary water quality in most cases given the effects of tidal flushing. Estuary TN does undergo a very small decrease when re-use is used or the STP is upgraded. These results do not necessarily indicate negligible impact, only that the impact is not noticeable given the coarseness of output values in the CLAM model. A finer resolution of output states may allow any changes to be seen more clearly. If the output states reflect the level of sensitivity of these pollutants that is of concern to the community then this is indicative that the system may not respond significantly to these management options. Otherwise a finer resolution may be necessary to ensure this is the case. Both upgrades and re-use had very minor beneficial impacts on seagrass beds, by slightly reducing the likelihood of large decreases in seagrass beds. Impacts of urban development in combination with STP management are very similar to those of urban development in isolation although the STP options do mitigate increases in nutrient inputs to the estuary. Increases in TN with further development are mitigated more effectively with the STP upgrade compared with effluent re-use although the difference in the level of these impacts is relatively minor.

Conclusions

Overall the results indicate that the nature of tidal flushing in Deep Creek estuary assists in maintaining fairly good estuary water quality. Even though this is the case, human action can have both positive and negative effects on water quality and subsequent ecological parameters. While improvements or impacts are often small they may still be significant and should be considered carefully. Where no impact is shown users should carefully consider whether or not the level of aggregation in the state variables (ie. the states used to describe outputs) is appropriately detailed. It should also be noted that information on flushing was seen as one of the large gaps in putting the CLAM model together for Deep Creek. While current results indicate that the estuary is fairly well flushed, this is based on fairly poor quality information which is likely to be inaccurate. In particular the differences of flushing and subsequent water quality spatially across the estuary are not understood and have not been accounted for in the model such that areas of the estuary could be subject to very poor water quality due to limited flushing but this would not be captured by the current information in the model. Conducting a more detailed processes study of the estuary is essential to this understanding. Such a study should then be used to update the Deep Creek CLAM framework and model data.

1 INTRODUCTION

This Sustainability Assessment report is based on results from the Coastal Lake Assessment and Management (CLAM) tool for Deep Creek. 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 Deep Creek CLAM and key data gaps which should be a priority for data collection
- provide a useful analysis of options of first concern to Council and other key stakeholders which can be incorporated in decision making and other planning activities on these issues; and,
- illustrate the way in which the CLAM tool can be used to show the trade-offs involved in managing the lake system.

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

1.1 What is CLAM?

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

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

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

- To document in a transparent way data and assumptions available to be used in making a decision;
- To allow such data and assumptions to be applied repeatedly over many (often 100,000's) iterations in a consistent manor 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 DEEP CLAM

2.1 Conceptual framework

The Deep Creek 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 riparian management. Definitions for all nodes in this conceptual framework are given in Appendix 1.

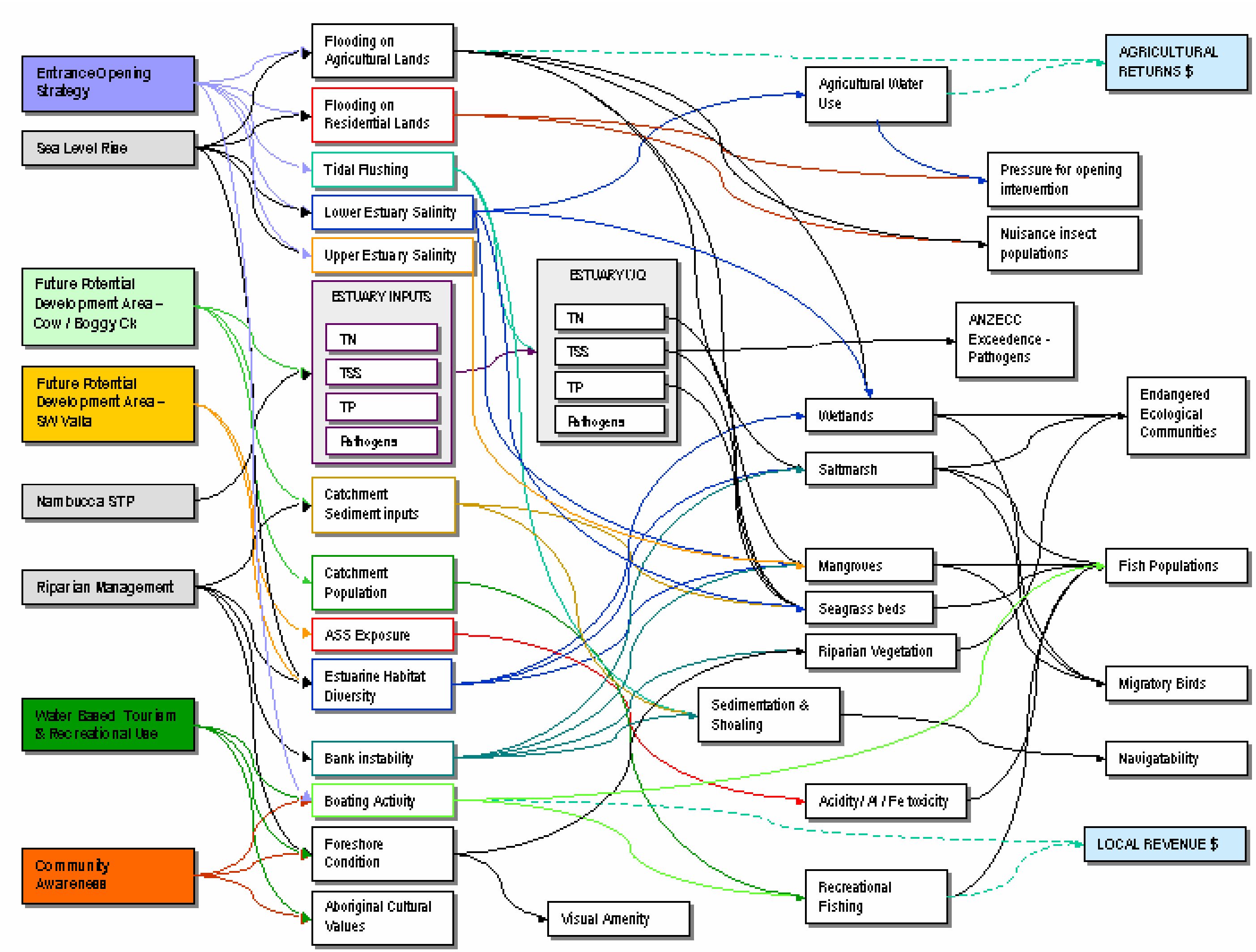

Figure 1. Deep Creek conceptual framework

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 a 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 Deep Creek is then given. This statement was provided by Damon Telfer who put together the data for the Deep CLAM.

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

Table 1. Data quality in the Deep CLAM

Node	Quality of Data	Reason	Suggested improvements
Aboriginal cultural values	Poor	Based on assumptions and local knowledge	Expert review of results and/or more detailed study of impacts of scenario options on cultural heritage values.
Acid AL Fe toxicity	Poor	Based on assumptions and local information	Model interaction between salinity, flushing and toxicity, improve information on spatial heterogeneity of estuary processes would assist. Expert review of current data.
Acid Sulphate Soil Exposure	Average	Based on assumptions and local data	Expert review of results. More detailed mapping and modelling required for more quantitative results.
Agricultural returns	Average	Based on assumptions, local studies and local knowledge.	Address gaps in information on effectiveness of floodgate option. Review of information by local experts.
Agricultural water use	Average	Based on assumptions and local knowledge	Expert review of information.
ANZECC exceedence pathogens	Very good	Based on definitions	Data quality to be checked through input pathogens and estuary pathogens. This node is only definitional.
Bank instability	Poor	Based on assumptions and some local and non-local knowledge.	More detailed investigation of bank erosion and stability, improved understanding of effects of boat management options on behaviour. Expert review of results.
Boating Activity	Poor	Based on assumptions and limited local knowledge.	Information on actual use of the lake by boats (frequency, volume, speeds etc) could be collected. Expert review of data.
Catchment population	Average	Based on detailed information on new developments.	Impact of tourist numbers ignored. Also growth in currently developed areas of the catchment has been ignored.

Catchment Sediment inputs	Very Poor	Based on unsupported assumptions. No local data available.	Improved sediment modelling as well as data on bank erosion and instability. Expert review of data.
Endangered Ecological Communities	Poor	Based on assumptions and basic local knowledge.	Mapping of endangered ecological communities is lacking. Expert review of data and assumptions.
Estuarine Habitat Diversity	Very poor	Based on unsupported assumptions. No local data available.	Quantitative data on estuarine habitat diversity and influence of factors such as depth and water quality on this.
Estuary input – Pathogens	Good	Uses a basic pathogen model using local data for inputs and literature supported assumptions.	Improved pathogen modelling and verification of results with monitoring data. Expert review of data.
Estuary input – TN	Good	Based on an uncalibrated model using good local data.	Expert review of data. Verification of results against monitored water quality data.
Estuary input TP	Good	Based on an uncalibrated model using good local data.	Expert review of data. Verification of results against monitored water quality data.
Estuary input – TSS	Good	Based on an uncalibrated model using good local data.	Expert review of data. Verification of results against monitored water quality data.
Estuary WQ – Pathogens	Poor	Uses uncalibrated model which does not take into account differences in flushing time across the estuary. Some local data available for runs.	Information on flushing times across the estuary required. Data on freshwater inflows required.
Estuary WQ – TN	Poor	Uses uncalibrated model which does not take into account differences in flushing time across the estuary. Some local data available for runs.	Information on flushing times across the estuary required. Data on freshwater inflows required.
Estuary WQ – TP	Poor	Uses uncalibrated model which does not take into account differences in flushing time across the estuary. Some local data available for runs.	Information on flushing times across the estuary required. Data on freshwater inflows required.
Estuary WQ – TSS	Poor	Uses uncalibrated model which does not take into account differences in flushing time across the estuary. Some local data available for runs.	Information on flushing times across the estuary required. Data on freshwater inflows required.
Fish Populations	Poor	Based on assumptions. No local data available.	Expert review of data. Collection of base line data on fish populations as well as study of population reaction to pressures such as fishing and water quality.

Flooding on agricultural lands	Very Poor	Based on assumptions. Limited local knowledge and data available.	Better topographic data is required. Also more detailed assessment of climate and wave surge height effects on flooding and entrance opening would be useful. Expert review of current data required.
Flooding on residential lands	Very Poor	Based on assumptions. Limited local knowledge and data available.	Better topographic data is required. Also more detailed assessment of climate and wave surge height effects on flooding and entrance opening would be useful. Expert review of current data required.
Foreshore condition	Very Poor	Based on unsupported assumptions.	Local data on foreshore condition baseline required as well as information on effects of management changes on condition.
Lower Estuary Salinity	Average	Based on uncalibrated model. Coarse local input data available. No verification has been done.	More detailed information on freshwater inflows. Connections between upper and lower estuary. More detailed modelling of flushing and its influence on salinity.
Mangroves	Poor	Based on literature assumptions. No local data or knowledge available to verify.	Expert review of data. Study of local mangrove populations for impacts of changes in lake level and water quality.
Migratory birds	Very Poor	Based on assumptions. Little local data or knowledge available.	Local data on migratory birds and their dependence on various habitat types.
Navigability	Poor	Based on assumptions and some local knowledge.	Data on boat use of the estuary required. Also information on navigability under different water levels and entrance conditions.
Nuisance insect populations	Very Poor	Based on unsupported assumptions. No local data or knowledge available.	Expert review of data. Collection of primary data on nuisance insect populations during flood and non-flood periods.
Pressure on opening intervention	Poor	Based on assumptions. Limited local data available.	Expert review of data. Survey data could be collected on stakeholder attitudes to entrance opening and/or historic local media sources could be reviewed.
Recreational fishing	Poor	Based on assumptions. Regional data has been extrapolated.	Local data on recreational fishing in the estuary by residents and by holiday makers required.
Riparian vegetation	Very poor	Based on unsupported assumptions. No local data available.	Expert review of data. Collection of data on extent of riparian vegetation and links to bank instability.

Saltmarsh	Poor	Based on literature assumptions. No local data available.	Data on saltmarsh extent and dynamics for the estuary. Expert review of current information.
Seagrass beds	Poor	Based on literature assumptions and local knowledge.	Data on seagrass extent and dynamics for the estuary. Expert review of current information.
Sedimentation and Shoaling	Poor	Based on assumptions and local knowledge.	Expert review of data. Detailed process study of the estuary including effects of sediment delivery and changes in tidal flushing.
Tidal Flushing	Average	Based on an uncalibrated model. Local data used as inputs. No data available for verification.	More detailed process study of the estuary. Expert review of data.
Upper Estuary Salinity	Average	Based on an uncalibrated model. Local data used as model input.	More detailed process study considering freshwater inflows and connectivity between upper and lower estuary required.
Visual amenity	Very poor	Based on unsupported assumptions. No local data available.	Expert review of data. Survey of local residents and holiday makers.
Wetland	Very poor	Based on unsupported assumptions. No local data available.	Expert review of data. Collect data on extent, condition and dynamics of wetlands.

Priority data collection areas identified by Damon Telfer are:

- Information on the processes occurring in the estuary, in particular flushing of the system and understanding of the spatial nature of flushing in the estuary (which parts are well flushed, where are the connections within the estuary, are parts of the estuary isolated or more likely to be impacted on by water quality changes given differences in flushing regime);
- Data and modelling of freshwater inflows to the estuary;
- Better topographic data on the estuary and foreshore areas. This is needed at a fine scale to allow estuary processes to be understood and to give a better idea of flooding impacts.

3 SCENARIOS

In order to develop this Sustainability Assessment analysis a relatively small subgroup of scenarios were selected from the 20,736 available in the Deep CLAM. In was decided to focus on the following scenarios:

- Entrance management;
- Riparian management;
- Urban development with no change to the STP; and
- Urban development with STP upgrades.

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 Entrance management

As an ICOLL (Intermittently Open/Closed Lake or Lagoon), the entrance of Deep Creek estuary is subject to temporary closure during periods of prolonged low freshwater flows and when coastal wave and wind conditions build the sand berm at the estuary mouth.

Currently, it is the agreed policy of the Nambucca Shire Council and Department of Natural Resources to intervene and artificially open the entrance when the height of the estuary water reaches AHD 0.95 at "The Glen" at Hyland Park.

This scenario option allows for an assessment of the possible impacts of opening the entrance of Deep Creek at different AHDs given certain management actions are undertaken to alleviate identified issues with flooding and infrastructure.

The scenario choices are:
1. No change (artificially open at 0.95m AHD at Hyland Park)
2. Eliminate height critical infrastructure issues (eg. floodgates, irrigation offtakes) and allow natural opening
3. Utilise retaining structures to eliminate residential flooding and allow natural opening
4. Do options 2 and 3 above but open at new agreed height if WQ exceeds ANZECC Pathogen levels for a given time period

3.2 Riparian management

The importance of riparian vegetation to stream bank stability, sediment and nutrient retention, water quality, and waterway health has been well documented in Australia (Price and Lovett, 1999). In terms of riparian management, maintaining an adequate riparian buffer can greatly assist the maintenance of riparian functions.

Buffer zones can be effective at removing nutrient and sediment inputs to streams by restricting the direct use of land beside the stream and by processing water that has been transported into the riparian zone. However, their effectiveness is influenced by characteristics such as the hydrology, soil type, vegetation type, and mode of transport to streams (Parkyn, 2004).

The consensus in the literature is that grass buffer strips are effective at filtering sediment and sediment-associated pollutants (particulate P and N) from surface runoff. However they are less effective in removing soluble nutrients such as nitrate, ammonia, and dissolved P (Parkyn, 2004). Well-vegetated stream banks are also essential for maintaining bank stability and preventing direct sediment and nutrient inputs into waterways through bank erosion (Price and Lovett, 1999).

The scenarios used in the Deep Creek CLAM for riparian management seek to test the effect of adopting the following buffer widths and management policies:

1. No change
2. Buffer zones of 20m acquired for new developments or subdivisions
3. Provide incentives for improved management aimed at creating 20m buffers.
4. Require agricultural landholders to control stock access along major streams by fencing a minimum 5m buffer.

3.3 Urban development in Cow/Boggy creek

A number of recommendations have been drafted for development control in the Cow Creek and Boggy Creek future urban development areas as part of the DRAFT Nambucca Shire Structure Plan Review 2006.

Although the DRAFT document has not yet been reviewed by Nambucca Council or been subject to community review the scenarios modelled here represent possible scenarios for development that could have effects on the Deep Creek Estuary. The scenarios should be updated in the future once the Structure Plan has been completed at which time more detailed and accurate information on potential options for future development in the Cow Creek and Boggy Creek areas may be known.

The scenarios developed for the Deep Creek CLAM are:
1. No development of Cow Creek/Boggy Creek area.
2. Develop Cow Creek/Boggy Creek area as a majority residential development (as per Sutherland draft)
3. Develop Cow Creek/Boggy Creek area as a majority commercial/industrial development (60%).

3.4 Urban development in South West Valla

A number of recommendations have been drafted for development control in the "South West Valla Beach" future urban development areas as part of the DRAFT Nambucca Shire Structure Plan Review 2006. This land is currently zoned 1(d) for future urban development but as yet no proposals are before Council.

Although the DRAFT document has not yet been reviewed by Nambucca Council or been subject to community review the scenarios modelled here represent possible scenarios for development that could have effects on the Deep Creek Estuary. The scenarios should be updated in the future once the Structure Plan has been completed at which time more detailed and accurate information on potential options for future development in the "South West Valla Beach" future urban area may be available.

The scenarios developed for the Deep Creek CLAM are:

1. No development of Valla 1(d) lands immediately east of the Pacific Hwy.
2. All 1(d) lands developed as medium density residential with 12 dwellings/ha.
3. 1(d) lands developed but discounted by 32% to remove environmental constraints (determined through removal of preliminary environmental constraint areas such as wetlands, water bodies, heavily vegetated areas) and developed as a medium density urban development (ie. 12 dwellings/hectare).

3.5 STP management

The Nambucca Sewerage Treatment Plant services the residents of Valla, Valla Beach, Hyland Park and Nambucca. The existing plant consists of a trickling filter plant, commissioned in 1970 that has a nominal capacity of about 5,000 equivalent persons (EP). An extended aeration tank, was added in 1986 essentially doubling the capacity. The plant also has two sludge lagoons, sludge drying beds and a 15,000 EP inlet works and chemical dosing system for phosphorus removal. Currently, effluent passes through a catch pond and a series of maturation ponds before it is released to an upper branch of Deep Creek (DoC, 2006).

Moderate population growth is expected in the future along with several small developments within the Deep Creek Catchment. Two major land releases at South Valla Beach and in the Cow/Boggy Creek area may potentially occur in the next 10 years. The collection and transportation system and the STP will require upgrading to accommodate the future population expected. The STP is also to be upgraded to meet future expected increased effluent quality requirements (DoC, 2006).

The location of the STP makes reuse for agricultural purposes difficult as the plant is actually situated within Nambucca State Forest. Recycling of water for industrial uses is also not currently under consideration (T. Pedlow, pers. comm., 2006). Despite this an option to test the potential effects of diversion of some of the treated effluent currently discharged in the tributary/wetland to a reuse/recycling option has been included in the modelling.

The scenarios developed related to the Nambucca STP used in the Deep Creek CLAM are:

1. No change (current treatment and capacity)
2. Upgrade plant (as per Concept Design Report, DoC, 2006) to improve treatment standard and provide capacity in line with predicted population increase (as per census data) and Cow Creek/Boggy Creek development.
3. Initiate a treated effluent re-use program which would recycle and reuse 30% of treated effluent for agricultural irrigation as an alternative disposal mechanism to the current discharges into the Deep Creek estuary.

4 RESULTS FROM SCENARIO RUNS

4.1 Entrance management

Four entrance opening options were considered including the 'do nothing' option. These options had no impact on 19 nodes: Estuary input - TN; Estuary input - TSS; Estuary input - TP; Estuary input - Pathogens; Catchment sediment inputs; Catchment population; Acid Sulphate Soil Exposure; Estuarine Habitat Diversity; Bank instability; Foreshore condition; Visual amenity; Aboriginal cultural values; Estuary WQ - Pathogens; Acid Al Fe toxicity; Riparian Vegetation; ANZECC exceedence pathogens; Endangered Ecological Communities; Agricultural returns; and Fish populations. Impacts on other nodes are summarised in Table 2.

Table 2. Summary of impacts of Entrance management

	Eliminate height critical infrastructure and allow natural opening	Retaining structures and natural opening	Option 2 and 3 with ANZECC trigger
Agricultural water use	No impact	No impact	Small chance of no irrigation
Flooding on agricultural lands	Moderate increase	Moderate increase	Small increase
Flooding on residential lands	Moderate increase	Moderate decrease	Moderate to large decrease
Tidal flushing	Small decrease	Small decrease	Large decrease
Lower Estuary salinity	No impact	No impact	Large increase
Boating activity	Small to moderate increase	Small to moderate increase	Small to moderate increase
Estuary WQ - TN	Very small decrease	Very small decrease	Moderate decrease
Estuary WQ - TSS	Small decrease	Small decrease	Small to moderate decrease
Estuary WQ - TP	No impact	No impact	Very small decrease
Wetlands	Very small increase	Very small increase	Very small increase
Saltmarsh	Very small increase	Very small increase	No impact
Mangroves	Very small increase	Very small increase	Very small decrease
Seagrass Beds	Very small increase	Very small increase	Very small decrease
Sedimentation and Shoaling	Small to moderate decrease	Small to moderate decrease	Small to moderate decrease
Recreational Fishing	Moderate increase	Moderate increase	Moderate increase
Pressure for opening intervention	Very small increase	Very small decrease	Very small decrease
Nuisance insect populations	Small increase	Small increase	Very small increase
Fish populations	No impact	No impact	Very small decrease
Migratory birds	Very small increase	Very small increase	Very small increase
Navigatability	Very small increase	Very small increase	Very small increase
Upper Estuary salinity	No impact	No impact	Small increase

This table shows that changes to entrance opening are likely to have very small to moderate impacts on estuary water quality parameters. The largest impact, a moderate decrease, is experienced for estuary TN when both options 2 and 3 and an ANZECC trigger are used. In consequence of these relatively small impacts, ecological impacts are also small, with most parameters, such as wetlands, saltmarsh, seagrass beds and mangroves experiencing a very small increase. The greatest impact is on flooding of agricultural and residential lands and on recreational fishing which experiences a moderate increase. Agricultural lands experience a moderate increase in flooding under the first two options, and a small increase under ANZECC trigger levels. Residential flooding impacts are more complex with a moderate increase for a return to natural opening, and small to moderate decreases for other options.

The impacts of entrance opening on estuary TN are shown in more detail in Figure 2.

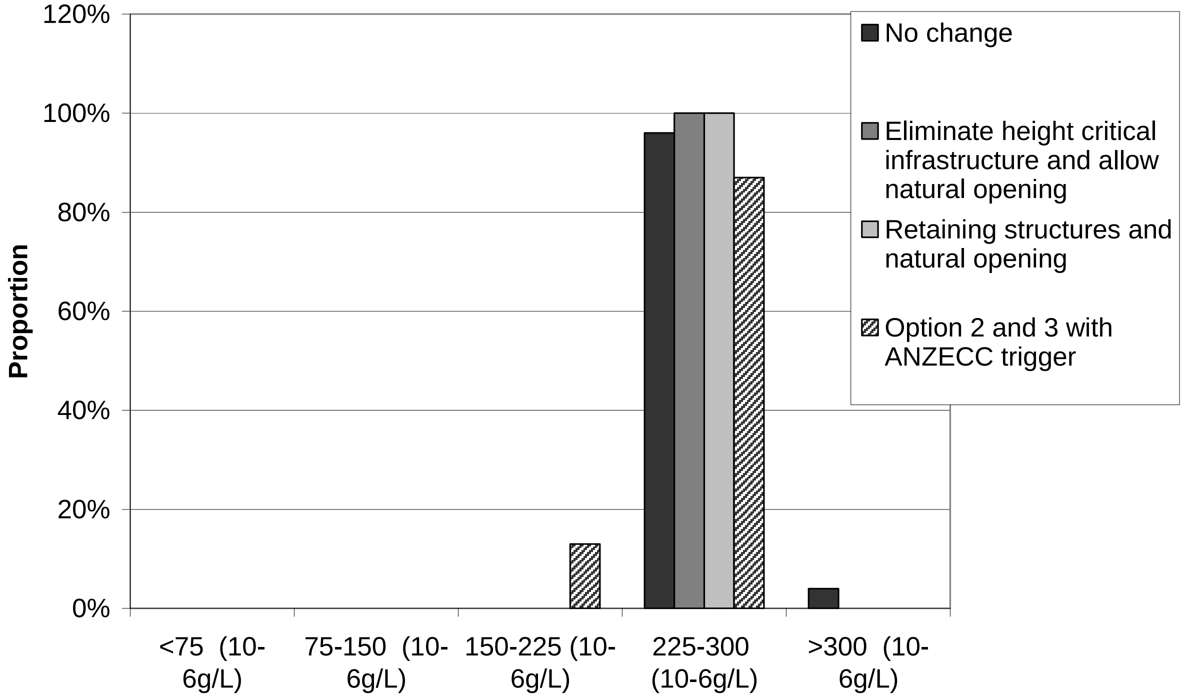

Figure 2. Impact of entrance opening on estuary TN

This shows that under the base case option (do nothing) there is a small chance of extremely high levels of TN (>300 10^{-6} g/L). All other entrance opening options remove this chance, while using the ANZECC trigger decreases estuary TN further such that there is now a small to moderate chance of smaller TN levels being experienced (150-225 10^{-6} g/L).

The impacts of entrance opening on flooding of residential lands is illustrated in Figure 3.

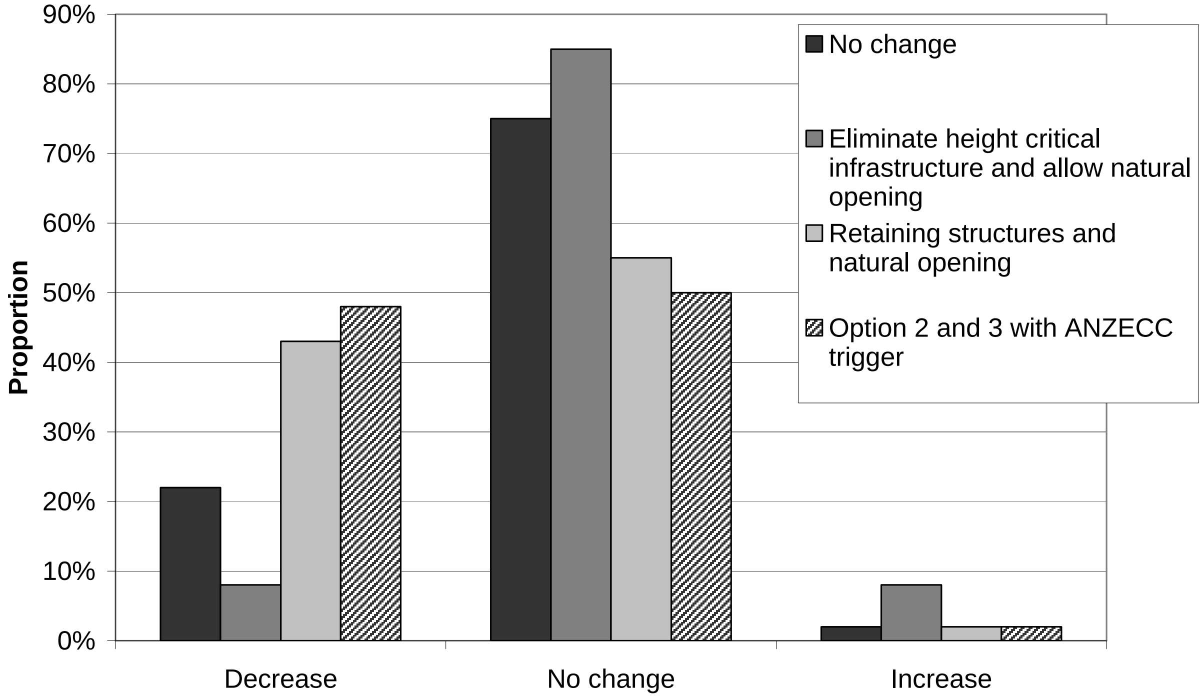

Figure 3. Impact of entrance opening on flooding of residential lands

This figure shows the complexity of impacts of entrance opening regime on residential flooding. Eliminating height critical infrastructure and allow natural opening leads to an increased probability of an increase or no change in flooding while other options show a substantially greater probability of a decrease in flooding.

4.2 Riparian management

Four riparian management options were considered. Overall these had no impact on 23 nodes: Agricultural water use; Flooding on agricultural lands; Flooding on residential lands; Tidal flushing; Lower Estuary salinity; Estuary input - TN; Estuary input - TSS; Estuary input - TP; Catchment population; Acid Sulphate Soil Exposure; Boating activity; Aboriginal cultural values; Estuary WQ - TN; Estuary WQ - TSS; Estuary WQ - TP; Estuary WQ - Pathogens; Acid Al Fe toxicity; Pressure for opening intervention; Nuisance insect populations; ANZECC exceedence pathogens; Agricultural returns; Upper Estuary salinity; and Recreational fishing. Interestingly this shows that riparian management has no impact on either estuary water quality inputs or final estuary water quality for most water quality parameters. This implies that changes are too subtle to have an impact at the scale of the outputs – that is, given the level of aggregation in the description of water quality states no change is observed. This may mean that there is no impact or that the impact is too slight given the level of aggregation of the outputs to be observed. Users of the model should be aware of this assumption and should consider whether or not to add this link. Table 3 provides a summary of the impacts on other nodes of riparian management options.

Table 3. Summary of impacts of riparian management

	Buffers for new developments or subdivisions	Buffer incentives offered	Agricultural buffers required
Estuary input - Pathogens	No impact	Large decrease	Large decrease
Catchment sediment inputs	Moderate decrease	Moderate decrease	Moderate decrease
Estuarine Habitat Diversity	Small to moderate increase	Moderate increase	Small to moderate increase
Bank instability	Moderate decrease	Moderate decrease	Shift to no change
Foreshore condition	Moderate to large increase	Moderate to large increase	Moderate to large increase
Wetlands	Small increase	Moderate increase	Small increase
Saltmarsh	Moderate increase	Moderate to large increase	Small increase
Mangroves	Small increase	Moderate increase	Very small decrease
Seagrass Beds	Very small increase	Very small increase	Very small increase
Sedimentation and Shoaling	Moderate decrease	Moderate decrease	Small decrease
Riparian Vegetation	Moderate increase	Moderate increase	Small increase
Fish populations	Moderate increase	Moderate increase	Small increase
Migratory birds	Small increase	Moderate increase	Very small increase
Navigatability	Very small increase	Very small increase	Very small increase
Endangered Ecological Communities	Small to moderate increase	Moderate increase	Very small increase
Visual amenity	Very small increase	Very small increase	Very small increase

This table shows that while riparian management is not expected to have noticeable effects on most estuary water quality parameters, it is likely to have some impact, in some cases moderate to large impacts, on ecological outcomes. These impacts come about through the impact of riparian management on foreshore condition, which in turn affects riparian vegetation and endangered ecological communities, as well as through estuarine habitat diversity and catchment sediment input which have impacts on mangroves, seagrasses and other ecological parameters. It should be noted that the exception on water quality is pathogen input, which is expected to experience a significant decrease when agricultural buffers are used (either through incentives or regulation).

Figure 4 shows the impacts of riparian management on estuarine habitat diversity.

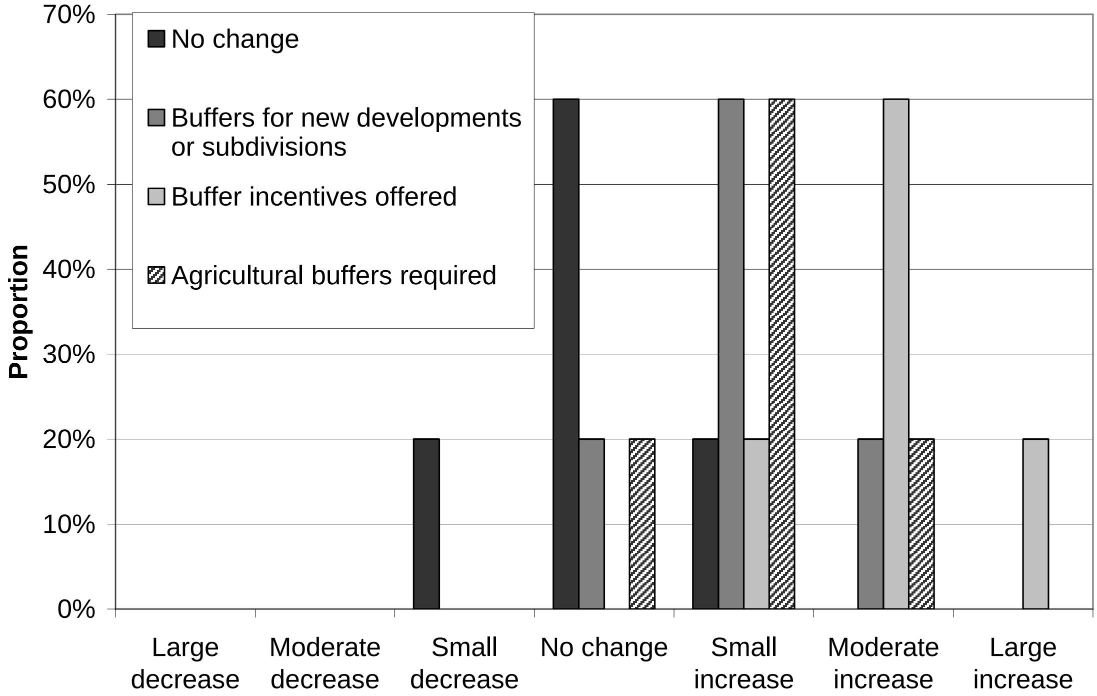

Figure 4. Impact of riparian management on estuarine habitat diversity

This figure shows that under the 'do nothing' option there is a 20% chance of a small decrease in estuarine habitat diversity, while the most probable outcome is no change. Implementing riparian management options shifts the probability such that there is now no chance of a small decrease, while the most probable outcome for buffers for new developments and subdivisions and where agricultural buffers are required becomes a small increase in habitat diversity and a 20% chance of a moderate increase. Offering buffer incentives leads to an even greater increase in estuarine habitat diversity, with the most probable outcome becoming a moderate decrease and a 20% chance of a large increase.

Figure 5 shows the impact of riparian management on sedimentation and shoaling.

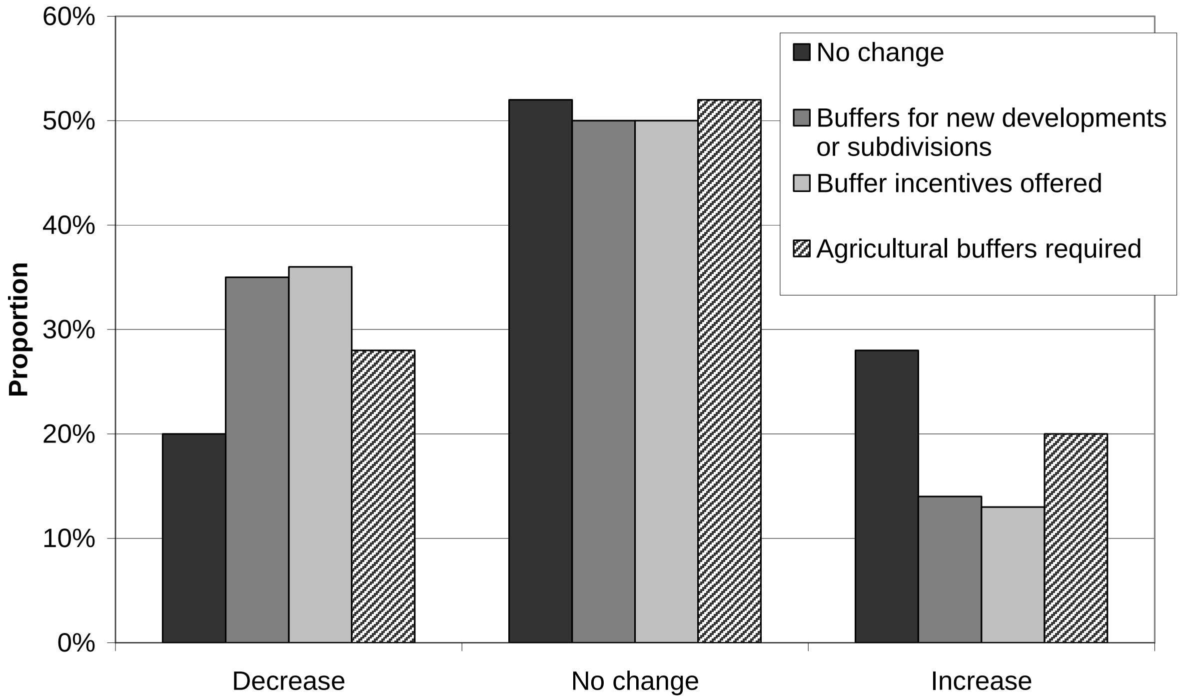

Figure 5. Impact of riparian management on sedimentation and shoaling

This figure shows that the greatest impact of riparian management on sedimentation occurs where buffer incentives are offered, followed closely by buffers for new developments and subdivisions. Agricultural buffers also decrease sedimentation and shoaling but by a smaller margin.

These results show that the best ecological and sedimentation outcomes are generally experienced under buffer incentives although all riparian management options have ecological and sedimentation benefits.

4.3 Urban development

Altogether 9 urban development options have been considered. These options are the combination of 3 scenarios for Cow/Boggy creek (CB) and 3 options for south west Valla (SW Valla). These combinations of options have been run and results are described in this section. In the next section a subset of these urban development options are run in combination with various STP management options. These urban development options have no impact on 22 nodes: Agricultural water use; Flooding on agricultural lands; Flooding on residential lands; Tidal flushing; Lower Estuary salinity; Estuary input - Pathogens; Bank instability; Foreshore condition; Visual amenity; Boating activity; Aboriginal cultural values; Estuary WQ - TP; Estuary WQ - Pathogens; Wetlands; Riparian Vegetation; Pressure for opening intervention; Nuisance insect populations; ANZECC exceedence pathogens; Agricultural returns; Upper Estuary salinity; and Navigatability. As for riparian management, urban development is seen to have no impact on some water quality parameters (pathogens, estuary TP). However other water quality parameters, such as TN and TSS, are now impacted. Table 4 summarises the impact of urban development options on impacted nodes.

Table 4. Summary of impacts of urban development

	Residential CB	Commercial CB	Develop SW Valla all 1(d)	Develop SW Valla all 1(d), Residential CB	Develop SW Valla all 1(d), Commercial CB	Develop SW Valla constrained	Develop SW Valla constrained, Residential CB	Develop SW Valla constrained, Commercial CB
Estuary input - TN	Moderate increase	Moderate increase	Large increase	Large increase	Large increase	Large increase	Large increase	Large increase
Estuary input - TSS	Large increase	Large increase	Moderate increase	Large to very large increase	Large to very large increase	Moderate increase but reduced extreme large events	Large increase	Large to very large increase
Estuary input - TP	Small increase	No impact	Moderate increase	Moderate to large increase	Moderate increase	Moderate increase	Moderate increase	Moderate increase
Catchment sediment inputs	No impact	No impact	No impact	Moderate increase	Moderate increase	No impact	Moderate increase	Moderate increase
Acid Sulphate Soil Exposure	No impact	No impact	Small increase	Small increase	Small increase	No impact	No impact	No impact
Estuarine Habitat Diversity	No impact	No impact	Small to moderate decrease	Small to moderate decrease	Small to moderate decrease	No impact	No impact	No impact
Estuary WQ - TN	Very small increase	Very small increase	Small increase	Small increase	Small increase	Small increase	Small increase	Small increase
Estuary WQ - TSS	Moderate increase	Moderate increase	Moderate increase	Moderate increase	Moderate increase	Moderate increase	Moderate increase	Moderate increase
Saltmarsh	Small decrease	No impact	No impact	Small decrease	No impact	No impact	Small decrease	No impact
Mangroves	Small increase	No impact	No impact	Small increase	No impact	No impact	Small increase	No increase
Seagrass Beds	Very small decrease	Very small decrease	Small decrease	Small decrease	Small decrease	Small decrease	Small decrease	Small decrease
Sedimentation	No impact	No impact	No impact	Small	Small increase	No impact	Small increase	Small increase

and Shoaling				increase				
Acid Al Fe toxicity	No impact	No impact	Small increase	Small increase	Small increase	No impact	No impact	No impact
Migratory birds	No impact	No impact	Very small increase	Very small increase	Very small increase	No impact	No impact	No impact
Endangered Ecological Communities	No impact	No impact	Very small decrease	Very small decrease	Very small decrease	No impact	No impact	No impact
Catchment population	Large increase	Large increase	Large increase	Very large increase	Very large increase	Large increase	Very large increase	Very large increase
Recreational Fishing	Moderate increase	Moderate increase	Moderate increase	Large increase	Large increase	Moderate increase	Large increase	Large increase
Fish populations	Very small decrease	No impact	Very small decrease	Very small decrease	Very small decrease	Very small decrease	Very small decrease	Very small decrease

This table shows that the impacts of development on both water quality and ecological outcomes are fairly mixed. Both commercial and residential development of Cow/Boggy Creek leads to a moderate increase in the input of TN, and large increases in TSS. However, commercial development had no impact on TP inputs, while residential development could be expected to slightly increase inputs to the estuary. The development of all 1(d) lands in south west Valla leads to large increases in TN inputs as well as moderate increases in inputs of TSS and TN. Constrained development of 1(d) lands in south west Valla does not impact TP inputs relative to full development of this land, and there is little difference in TN inputs. Although TSS inputs still show a moderate increase, constrained development reduces the incidence of extreme TSS events. The results also show evidence of the cumulative impact of developments with negative consequences of the two developments together (for example TSS input) being greater than those of either in isolation. These impacts on pollutant inputs do not necessarily translate to worse water quality in estuary. For estuary TP no impact was seen for any option, while for estuary TN the changes lead to very small to small increases impacts. All options lead to a moderate increase in estuary TSS. The increase in catchment population leads to an increase in recreational fishing which is expected to induce a very small decrease in fish populations for most development options. Commercial development in Cow/Boggy Creek has no impact on recreational fishing.

Figure 6 shows the impact of urban development on input TN in more detail.

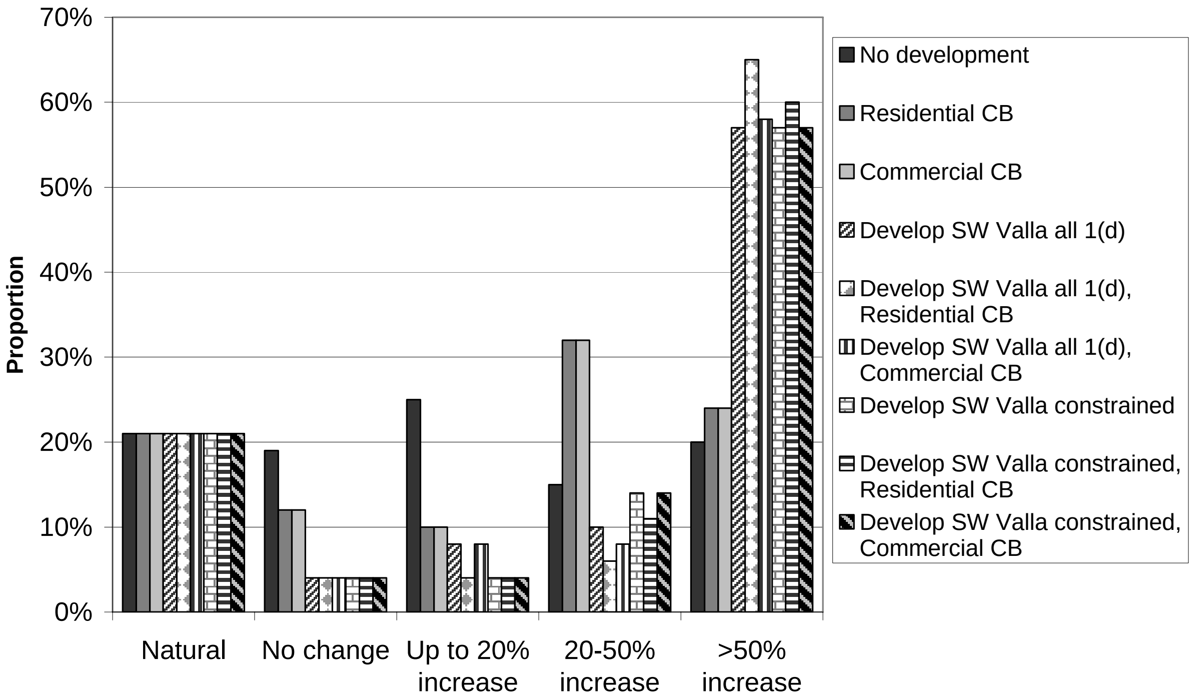

Figure 6. Impact of urban development input TN

This figure shows that under no development there is a 21% chance of input TN reaching natural levels, a 19% chance of no change and moderate probabilities (10-20%) of 20-50% increases and greater than 50% increases. There is no change in the probability of TN inputs reaching natural levels for all development. However, all scenarios indicate a greater probability of increased TN inputs. Development of south west Valla has a larger impact in TN inputs than development of Cow/Boggy Creek. Either Cow/Boggy Creek development option gives a 12% change of no change in TN inputs and a >30% chance in 20-50% increases in TN inputs. All development options for south west Valla show a <5% change of no change and very large probabilities (>50%) of a >50% increase in TN inputs. In most cases developing both Cow/Boggy Creek and south west Valla further increases the likelihood of elevated TN inputs. An exception to this is that the model suggests no further increase in TN inputs when constrained development of south west Valla 1(d) lands is combined with commercial development of Cow/Boggy Creek. Differences between residential and commercial development of Cow/Boggy Creek are apparent when combined with either south west Valla development option. Residential development shows a slightly higher chance of larger TN inputs than commercial development.

These changes in TN input do not lead to a similar magnitude of change in estuary TN due to the influence of tidal flushing. These impacts are shown in Figure 7.

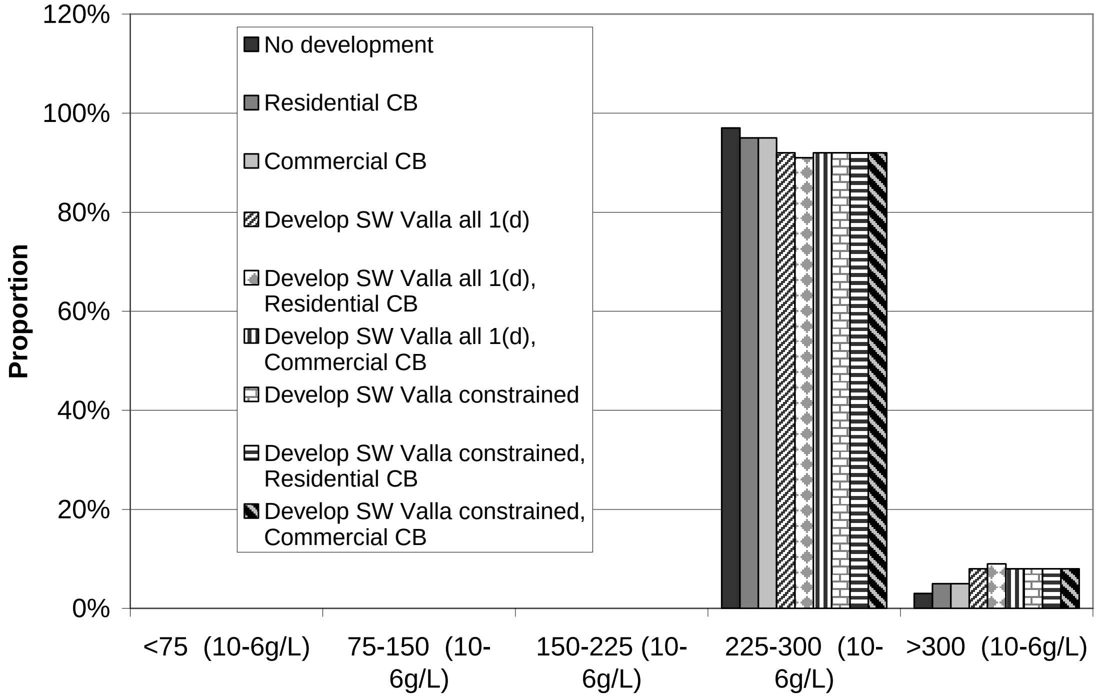

Figure 7. Impact of urban development on estuary TN

This figure shows that changes in estuary TN are much more subtle than those in input TN, because tidal flushing effectively dampens the response of the system to management changes. The greatest increase is experienced for the scenario combination where Cow/Boggy Creek is under residential development and all 1(d) land in south west Valla is developed but the difference to other scenarios is greatly reduced. A shift of 6% from the second highest band (225 to 300 x 10^{-6} g/L) to the highest band occurs for this case. Greater impacts may be observed if the description of the estuary TN states was more highly disaggregated in the 225 to 300 x 10^{-6} g/L and >300 x 10^{-6} g/L bands.

The complexity of water quality impacts leads to mixed impacts on ecological outcomes in the estuary. Figure 8 illustrates the impacts on seagrass beds.

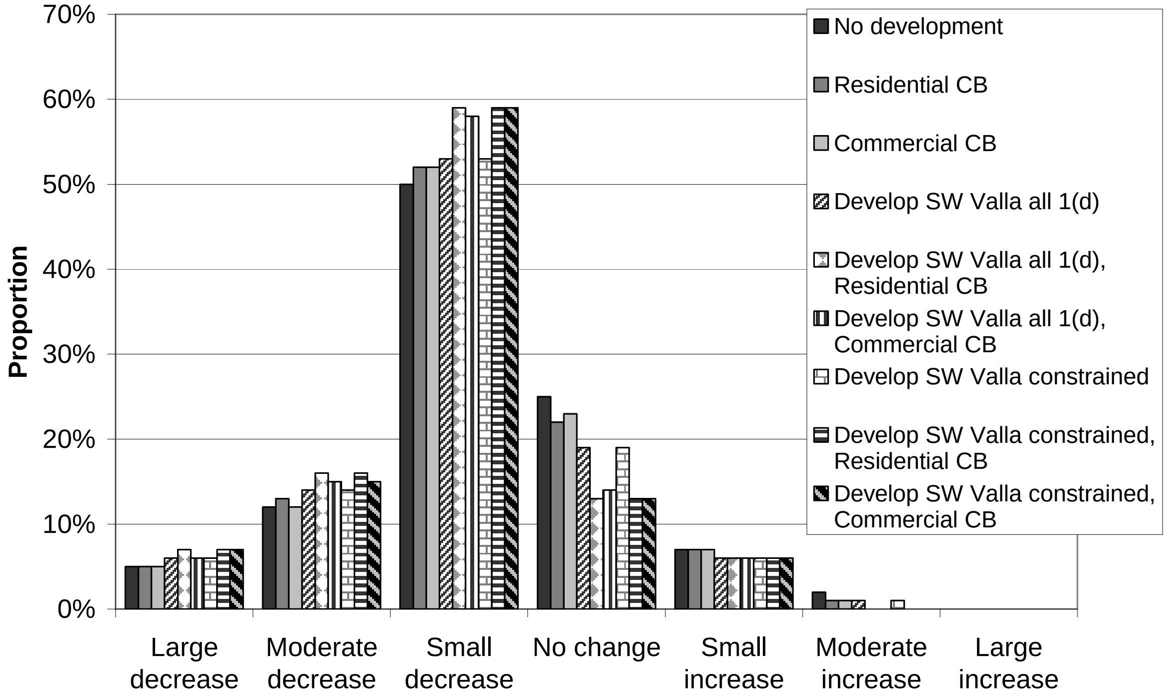

Figure 8. Impact of urban development on seagrass beds

This figure shows that all development options lead to a decrease in seagrass beds. The most negative impact occurs when development of SW Valla occurs on all 1(d) lands and Cow/Boggy creek is developed as a residential area. Similar impacts are experienced when SW Valla is under constrained development and Cow/Boggy Creek is developed as a residential area. The smallest impact is experienced when Cow/Boggy Creek is undertaken as either a commercial or residential development with no development occurring in SW Valla.

The impact of urban development on estuarine habitat diversity is shown in Figure 9. This figure shows quite clearly that negative impacts on estuarine habitat diversity are likely to occur from development of all 1(d) lands in SW Valla. Other scenarios have no impact.

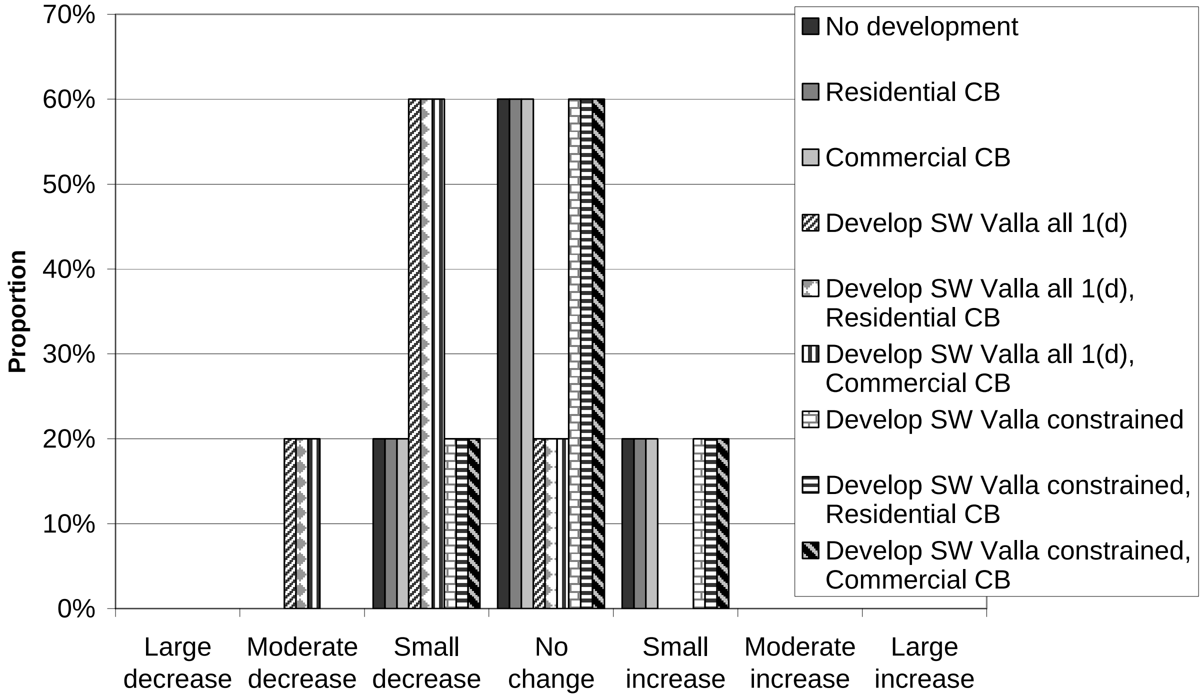

Figure 9. Impact of urban development on estuarine habitat

Overall these results show that while development options have a range of impacts on water quality from no impacts for some options to large and very large increases for other parameters, all development options are likely to lead to some negative consequences such as a decline in seagrass beds and increases in estuary TSS. Constraining development in SW Valla does lead to improvements in TSS inputs and dependant ecological outcomes relative to development on all 1(d) areas. Development of both areas generally leads to cumulative impacts that are worse than either in isolation.

4.4 Urban development with STP upgrades

Eleven combinations of STP upgrade and urban development options were considered. These combined the no change option with the other two options for STP upgrade (upgrade plant and effluent re-use), with all combinations of full development (ie. development of Cow/Boggy with development of SW Valla). Overall 20 nodes experienced no impact: Agricultural water use; Flooding on agricultural lands; Flooding on residential lands; Tidal flushing; Lower Estuary salinity; Bank instability; Foreshore condition; Boating activity; Aboriginal cultural values; Estuary WQ - TP; Estuary WQ - Pathogens; Wetlands; Riparian Vegetation; Pressure for opening intervention; Nuisance insect populations; ANZECC exceedence pathogens; Agricultural returns; Upper Estuary salinity; Visual amenity; and, Navigatability. As for urban development with no STP upgrade, changes have no impact on estuary TP and estuary pathogens, although in this case there are impacts on inputs of these pollutants. Table 5 provides a summary of impacts where these occur.

Table 5. Summary of impacts of STP management and urban development

	Upgrade treatment	Re-use	Residential CB, All 1(d) for SW Valla, upgrade treatment	Residential CB, All 1(d) for SW Valla, reuse	Residential CB, Constraints SW Valla, upgrade treatment	Residential CB, Constraints SW Valla, reuse	Commercial CB, All 1(d) for SW Valla, upgrade treatment	Commercial CB, All 1(d) for SW Valla, reuse	Commercial CB, Constraints SW Valla, upgrade treatment	Commercial CB, Constraints SW Valla, reuse
Estuary input - TN	Large decrease	Moderate decrease	Small to moderate decrease	Moderate increase	Small to moderate decrease	Small to moderate increase	Small decrease	Moderate increase	Small to moderate decrease	Small to moderate increase
Estuary input - TSS	No impact	No impact	Large increase	Large increase	Moderate increase	Moderate increase	Large increase	Large increase	Large increase	Large increase
Estuary input - TP	Large decrease	Small decrease	Moderate increase but reduced extreme large events	Moderate increase	Moderate increase but reduced extreme large events	Moderate increase	Moderate increase but reduced extreme large events	Moderate increase	Moderate increase but reduced extreme large events	Moderate increase
Estuary input - Pathogens	Large decrease	Large decrease	Large decrease	Large decrease	Large decrease	Large decrease	Large decrease	Large decrease	Large decrease	Large decrease
Catchment sediment inputs	No impact	No impact	Moderate increase	Moderate increase	Moderate increase	Moderate increase	Moderate increase	Moderate increase	Moderate increase	Moderate increase
Catchment population	No impact	No impact	Large increase	Large increase	Large increase	Large increase	Large increase	Large increase	Large increase	Large increase
Acid Sulphate Soil Exposure	No impact	No impact	Small increase	Small increase	No impact	No impact	Small increase	Small increase	No impact	No impact
Estuarine Habitat Diversity	No impact	No impact	Moderate decrease	Moderate decrease	No impact	No impact	Moderate decrease	Moderate decrease	No impact	No impact
Estuary WQ -	Small	Very small	No impact	Small	Very small	Very small	No impact	Small	No impact	Very small

TN	decrease	decrease		increase	decrease	increase		increase		decrease
Estuary WQ - TSS	No impact	No impact	Moderate increase	Moderate increase	Small increase	Small increase	Moderate increase	Moderate increase	Moderate increase	Moderate increase
Saltmarsh	No impact	No impact	Small decrease	Small decrease	No impact	No impact	Small decrease	Small decrease	No impact	No impact
Mangroves	No impact	No impact	Small increase	Small increase	No impact	No impact	Small increase	Small increase	No impact	No impact
Seagrass Beds	Very small incr ease	No impact	Small decrease	Small decrease	Small decrease	Small decrease	Small decrease	Small decrease	Small decrease	Small decrease
Sedimentation and Shoaling	No impact	No impact	Small increase	Small increase	Small increase	Small increase	Small increase	Small increase	Small increase	Small increase
Acid Al Fe toxicity	No impact	No impact	Small increase	Small increase	No impact	No impact	Small increase	Small increase	No impact	No impact
Recreational Fishing	No impact	No impact	Moderate increase	Moderate increase	Moderate increase	Moderate increase	Moderate increase	Moderate increase	Moderate increase	Moderate increase
Fish populations	No impact	No impact	Small decrease	Small decrease	Small decrease	Small decrease	Small decrease	Small decrease	Small decrease	Small decrease
Migratory birds	No impact	No impact	Very small increase	Very small increase	No impact	No impact	Very small increase	Very small increase	No impact	No impact
Endangered Ecological Communities	No impact	No impact	Very small decrease	Very small decrease	No impact	No impact	Very small decrease	Very small decrease	No impact	No impact

This table shows that management options for the STP are likely to lead to large decreases in pathogen inputs to the estuary. Upgrading the STP will also produce a reduction in TN and TP inputs, while re-use will likely lead to a moderate reduction in TN inputs and a small decrease in TP inputs. There is no impact on TSS inputs with either option. In most cases these changes do not lead to any impact on estuary water quality as the influence of tidal flushing dampens the effect. It may also be that the state descriptors of the pollutants are too coarse to allow changes to be picked up at the levels they are occurring. The only estuary water quality outcome that is impacted by STP management is estuary TN under upgrade and re-use which shows a small decrease and a very small decrease, respectively. The only other impact of STP management is to induce a very small increase in seagrass beds under the upgrade option. Impacts for STP management options combined with development options are mixed. TN inputs show a small to moderate decrease for all combinations of the STP upgrade treatment and development options. In contrast, all combinations of the re-use and development options show a small to moderate increase in TN inputs. TSS inputs are the same as for the development scenarios examined in section 4.3. The combined impact of development and STP options all lead to an increase in TP inputs although reduced extreme large events are seen for all scenarios that include the STP upgrade.

The impacts of urban development and STP management on estuary TN is shown in Figure 10.

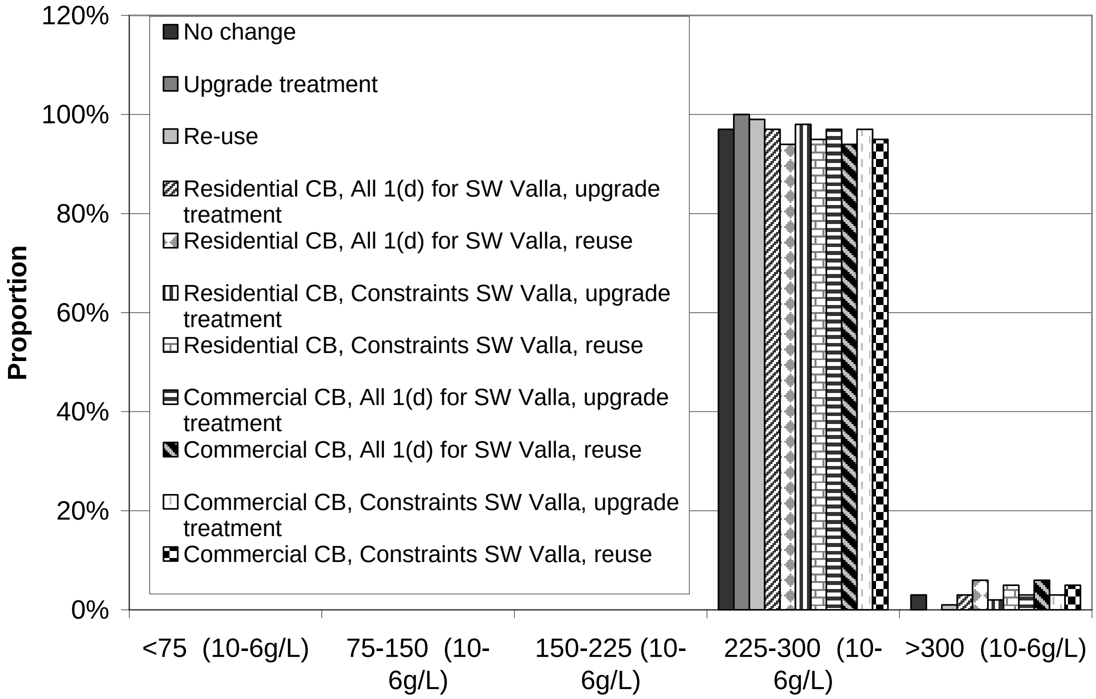

Figure 10. Impact of urban development and STP management on estuary TN

Tidal flushing dampens the impact of urban development and STP management scenarios on estuary TN. The most probable band is 225 – 300 x 10^{-6} g/L for all scenarios. Without development and with an STP upgrade, the TN concentration in the estuary is in this band 100% of the time, compared with 98% for the no change scenario and 96% for all combinations of re-use and urban development, With development, increases in TN are mitigated more effectively with the STP upgrade compared with effluent re-use although the difference in the level of these impacts are relatively minor.

The impact of urban development and STP management on seagrass beds is shown in Figure 11.

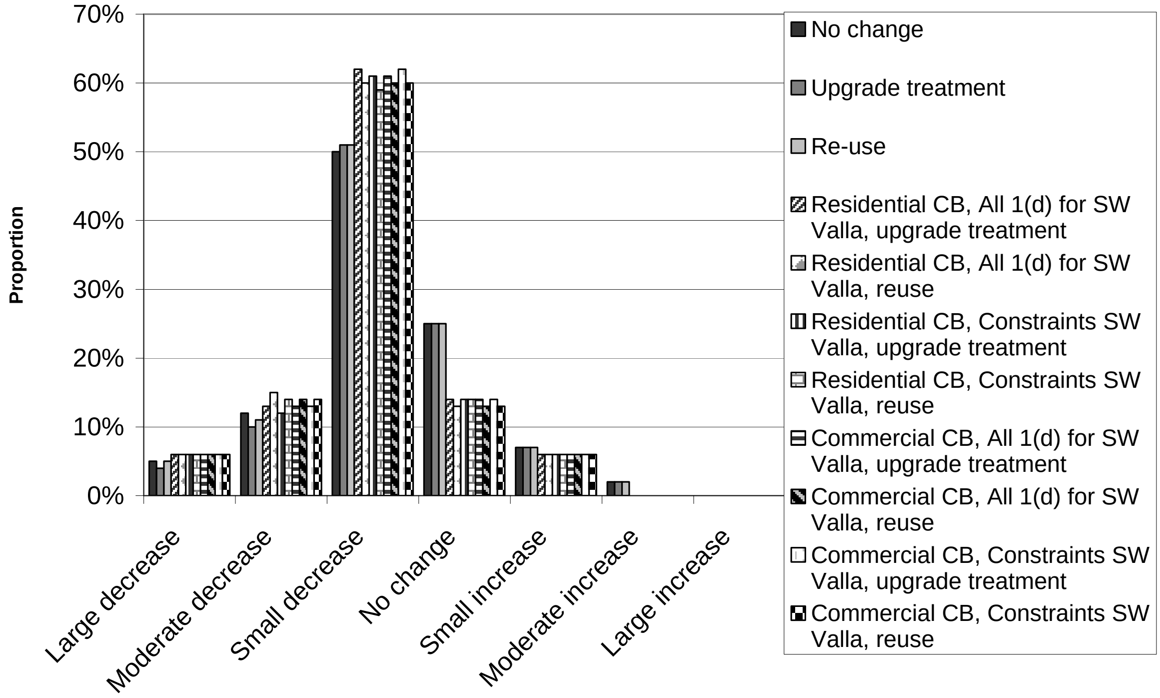

Figure 11. Impact of urban development and STP management on seagrass beds

This figure shows that, without further development, upgrading the STP or re-use of STP effluent have a very minor beneficial impacts with a slight decrease in the likelihood of moderate to large decreases in seagrass beds. With urban development there is an increased likelihood of a decrease in seagrass beds although impacts are mitigated by both upgrades to the STP and effluent re-use. Even with this mitigation the likelihood of a small decrease in seagrass beds increases from 50% for the no change scenario run to approximately 60%.

Overall these results show that while an STP upgrade or re-use of effluent have the potential to mitigate nutrient inputs to the Deep Creek, further development will lead to moderate to large increases in TN and TP inputs to the estuary regardless of the STP management options. In turn these impacts will affect ecological outcomes, particularly seagrass communities.

5 DISCUSSION OF THE RESULTS

This sustainability assessment report has provided a sample of results for management of the entrance, riparian management, urban development and management of the STP. These options are a small subset of the total number of scenarios which can be considered by the Deep 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 as well as for the potential for cumulative impacts of various options to impact on the system.

These results showed that changes to entrance opening are likely to have small to moderate impacts on estuary water quality parameters. The greatest water quality impact is a moderate decrease in estuary TN when both options 2 and 3 and an ANZECC trigger are used. These relatively small water quality impacts generate ecological impacts which are also small, with most parameters, such as wetlands, saltmarsh, seagrass beds and mangroves experiencing a very small increase. The greatest impact of entrance opening is on flooding of agricultural and residential lands and on recreational fishing which experiences a moderate increase. Agricultural lands experience a moderate increase in flooding under the first two options, and a small increase under ANZECC trigger levels. Residential flooding impacts are more complex with a moderate increase for a return to natural opening, and moderate to moderate to large decreases for other options.

In terms of riparian management it was shown that all three options: Buffers for new developments or subdivisions; Buffer incentives offered; and, Agricultural buffers required; lead to improvements in water quality and ecological outcomes. The best ecological and sedimentation outcomes are generally experienced under buffer incentives.

By contrast urban development has negative impacts on some water quality and ecological outcomes, particularly in terms of increasing estuary TSS and reducing seagrass beds. Two different development areas were considered – Cow/Boggy Creek and south west Valla. Scenarios for these areas showed that constraining development in SW Valla does lead to improvements in outcomes relative to development on all 1(d) areas. Development of both areas generally leads to cumulative impacts that are worse than either in isolation.

STP management is likely to reduce the input of pollutants such as pathogens and TN to the estuary but these are not large enough to have a noticeable effect on estuary water quality in most cases given the effects of tidal flushing. Estuary TN does undergo a very small decrease when re-use is used or the STP is upgraded. These results do not necessarily indicate no impact at all of these changes, only that the impact is not noticeable given the coarseness of output values in the CLAM model. A finer resolution of output states may allow any changes to be seen more clearly. If the output states reflect the level of sensitivity of these pollutants that is of concern to the community then this is indicative that the system may not respond significantly to these management options. Otherwise a finer resolution may be necessary to ensure this is the case. Both upgrades and re-use had very minor beneficial impacts on seagrass beds, by slightly reducing the likelihood of large decreases in seagrass beds. Impacts of urban development in combination with STP management are very similar to those of urban development in isolation although the STP options do mitigate increases in nutrient inputs to the estuary.

Overall these results indicate that the nature of tidal flushing in Deep Creek estuary assists in maintaining fairly good estuary water quality. Even though this is the case, human action can have both positive and negative effects on water quality and subsequent ecological parameters. While improvements or impacts are often small they may still be significant and should be considered carefully. Where no impact is shown users should carefully consider whether or not the level of aggregation in the state variables (ie. the states used to describe outputs) is appropriately detailed.

It should also be noted that information on flushing was seen as one of the large gaps in putting the CLAM model together for Deep Creek. While current results indicate that the estuary is fairly well flushed, this is based on fairly poor quality information which is likely to be inaccurate. In particular the differences of flushing and subsequent water quality spatially across the estuary are not understood and have not been accounted for in the model. Areas of the estuary could be subject to very poor water quality due to limited flushing but this would not be captured by the current information in the model. Conducting a more detailed processes study of the estuary is essential to this understanding. Such a study should then be used to update the Deep Creek CLAM framework and model data.

6 ACKNOWLEDGEMENTS

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APPENDIX 1. SUMMARY OF NODES IN THE DEEP CREEK CLAM TOOL

Node	Description	Output States	Units
Agricultural water use	This variable attempts to estimate the potential effects of increases in upper estuary salinity on agricultural water use	No change, Water too saline for pasture irrigation	
Flooding on agricultural lands	Estimates potential changes to the frequency of flooding on residential lands (qualitative)	Decrease, No Change, Increase	
Flooding on residential lands	Estimates potential changes to the frequency of flooding on residential lands (qualitative)	Decrease, No Change, Increase	
Tidal flushing	Percentage change in the estuary flushing time	>10% decrease, 10-5% decrease, 5-0% decrease, 0-5% increase, 5-10% increase, >10% increase	%
Lower Estuary salinity	Percentage change in the estuary flushing time	Decrease, no change, increase	
Estuary input - TN	Inputs of total nitrogen to Deep Creek Estuary	<10700, 10700-15230, 15230-18276, 18276-22845, >22845	kg/year
Estuary input - TSS	Inputs of total Suspended Sediment to Deep Creek Estuary	<100000, 100000-1200000, 1200000-1440000, 1440000-1800000, >1800000	kg/year
Estuary input - TP	Inputs of total phosphorous to Deep Creek Estuary	<500, 500-1600, 1600-1920, 1920-2400, >2400	kg/year
Estuary input - Pathogens	The concentration of faecal coliforms entering the lake from the catchment area	<14, 14-150, 150-1000, >1000	CFU/100ml (CFU = colony forming units)
Catchment sediment inputs	This variable attempts to estimate potential changes to bank instability (qualitative) under various options for riparian management and water based tourism and recreational use	Large decrease, Moderate decrease, Small Decrease, No change, Small increase, Moderate Increase, Large Increase	
Catchment population	This variable attempts to estimate potential changes to the population of the Deep Creek catchment	No Change, Increase up to 50%, Increase 50-100%, Increase >100%	%

Acid Sulphate Soil Exposure	Change in the likelihood of exposure and oxidation of acid sulphate soils	Decrease, No change, Increase	
Estuarine Habitat Diversity	Qualitative assessment of trends in the diversity of estuarine habitats in Deep Creek	Large decrease, moderate decrease, small decrease, no change, small increase, moderate increase, large increase	
Bank instability	This variable attempts to estimate potential changes to bank instability (qualitative) under various options for riparian management and water based tourism and recreational use	Decrease, No change, Increase	
Foreshore condition	Qualitative assessment of trends in nuisance insect populations	Decrease, No change, Increase	
Visual amenity	This unit models the change in Visual Amenity	Decrease, No Change, Increase	
Boating activity	Changes to the level of boating activity in Deep Creek Estuary (qualitative)	large decrease, moderate decrease, small decrease, no change, small increase, moderate increase, and large increase	
Aboriginal cultural values	This variable attempts to estimate the potential effects on aboriginal cultural values (qualitative) of changes to shoaling and sedimentation patterns	No change, Better respected	
Estuary WQ - TN	Total nitrogen in Deep Creek Estuary	<75, 75-150, 150-225, 225-300, >300	µg/L
Estuary WQ - TSS	Total Suspended Solids in Deep Creek Estuary	<5, 5-10,10-15,15-20, >20	g /m^{-3}
Estuary WQ - TP	Total phosphorous in Deep Creek Estuary	<10, 10-30, 30-50, >50	µg/L
Estuary WQ - Pathogens	The concentration of faecal coliforms in Deep Creek estuary	<14, 14-150, 150-1000, >1000	CFU/100ml (CFU = colony forming units)

Wetlands	Trends in the extent/distribution of floodplain wetland habitat (qualitative)	Large decrease, moderate decrease, small decrease, No change, Small increase, moderate increase, large increase	
Saltmarsh	The area of saltmarsh within Deep Creek estuary	Large decrease, moderate decrease, small decrease, no change, small increase, moderate increase, large increase	
Mangroves	Trends in mangrove extent/distribution (qualitative)	Large decrease, moderate decrease, small decrease, No change, Small increase, moderate increase, large increase	
Seagrass Beds	The area of seagrass within Deep Creek	Large decrease, moderate decrease, small decrease, no change, small increase, moderate increase, large increase	
Sedimentation and Shoaling	The continued deposition of sediment within lower Deep Creek Estuary from both catchment and marine sources	Decrease, No change, Increase	
Acid Al Fe toxicity	This unit models the change in potential Acid, Aluminium and Iron toxicity in the Deep Creek estuary	Decrease, No Change, Increase	
Riparian Vegetation	Trends in the extent/distribution/cover/condition of riparian vegetation (qualitative)	Large decrease, moderate decrease, small decrease, No change, Small increase, moderate increase, large increase	
Recreational Fishing	Changes to the level of recreational fishing activity in Deep Creek Estuary (qualitative)	large decrease, moderate decrease, small decrease, no change, small increase, moderate increase, and large increase	
Pressure for opening intervention	Estimates changes to the levels of pressure exerted by the public on public agencies to open the estuary entrance	Decrease, No Change, Increase	
Nuisance insect populations	Qualitative assessment of trends in nuisance insect populations	Decrease, No change, Increase	

ANZECC exceedence pathogens	The output of the lake pathogen node is related to relevant ANZECC guidelines	healthy, no aquaculture, no primary contact, no secondary contact	
Fish populations	Change in the populations of fish in the Deep Creek estuary	large decrease, moderate decrease, small decrease, no change, small increase, moderate increase, and large increase	
Migratory birds	This variable models the potential effects of changes to key habitats for migratory birds on migratory bird populations	Decrease, No Change, Increase	
Navigatability	This variable attempts to estimate the potential effects on navigatability (qualitative) of changes to shoaling and sedimentation patterns	Decrease, No Change, Increase	
Endangered Ecological Communities	Qualitative assessment of potential changes to the extent and distribution of estuary related endangered ecological communities (EECs) within Deep Creek catchment	Large decrease, moderate decrease, small decrease, no change, small increase, moderate increase, large increase	
Agricultural returns	This variable attempts to estimate the potential effects on agricultural returns (qualitative) of changes to agricultural water use (as a result of increased salinity) or the effects of changes to the frequency of flooding of agricultural lands	Decrease, No change, Increase	
Upper Estuary salinity	Percentage change in the upper estuary salinity	Decrease, no change, increase	

APPENDIX 2. ADDITIONAL SCENARIO GROUPS AVAILABLE IN THE CLAM TOOL

1. Community awareness
2. Sea level rise
3. Water based tourism and recreational use.

Community awareness

This scenario explores the possible impact upon the Deep Creek estuary and its catchment if the local resident and tourist population was educated to provide a greater understanding of how the ecosystem responds to certain actions/effects.

The scenarios used in the Deep Creek CLAM for community awareness are:

1. No community awareness program instigated
2. Educate tourist and local boat users about the impacts of wave wash
3. Educate the local community and tourists about the important values of foreshore and riparian vegetation
4. Educate local community and tourists about the importance of local indigenous cultural sites and values.

Very little locally relevant data is available on any of the above issues and as a result the data used in the model is purely qualitative.

Sea level rise

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

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

A normal distribution was assumed to describe the probabilities of the low, medium and high rates of sea level rise. Thus the assigned probabilities were 0.25, 0.5, 0.25 respectively. The probability of the various rates in sea level rise are dependant on the amount of carbon dioxide released into the atmosphere, which in turn in reliant on the national and global policies. Research into likely policies in the future is beyond the scope of this study.

REFERENCES:

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

Water based tourism and recreational use.

Despite the importance of tourism to the local economy, very little hard data is available on recreational and tourism use for Deep Creek estuary. An exception is the 2000-2001 Survey of Recreational Fishing in NSW, which estimated that fishing contributed in the vicinity of $40M per year to the mid north coast economy. Half of this figure was estimated to be spent on boating related items (DPI Fisheries, 2003).

Although no quantitative data is available, other recreational activities that are popular in the Deep Creek estuary including swimming, bird-watching, and enjoying the general aesthetics of the area.

In terms of future pressure and trends it is predicted that the population of Nambucca Shire could almost double over the next 2 decades (Nambucca Shire Draft 20 Year Structure Plan, Sutherland Koshy, 2006). If such an increase in population were to occur it is likely that recreational and tourism use of the estuary would also increase.

Due to the lack of available data, the scenarios options for Water Based Tourism and Recreational Use are currently limited to the assessment of the effects of increased boating use on the estuary.

The scenarios developed for the Deep Creek CLAM are:

1. No change
2. Improve boat ramp facilities but restrict motorised boating use via speed limits and no wash zones.
3. Increase unrestricted motorised boating use by 50%

REFERENCES:

DPI Fisheries (2003). Survey of Recreational Fishing in NSW. Department of Primary Industries. http://www.fisheries.nsw.gov.au/recreational/general/survey_of_recreational_fishing_in_new_south_wales

Sutherland Koshy Urban Design (2006). Nambucca Shire DRAFT Structure Plan. Unreleased DRAFT document prepared for the Nambucca Shire Council.