Belongil 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 Belongil 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 Belongil Creek CLAM for each node and also provides an assessment of key data gaps identified by Jennita Gay and Angus Ferguson in putting the Belongil CLAM together. These gaps are:

- There is a need for an improved hydrological model of the Belongil system that takes into account groundwater storage and gives better predictions of surface runoff. A model has been developed but has not yet been verified or calibrated with field data;
- Monitoring of inundation patterns of low-lying land;
- Application of a flood model of the system that would allow the impact of scenarios included in Belongil CLAM on black water and acid sulphate soil (ASS) inputs to be better captured. A flood model is currently being developed by the Snowy Mountains Engineering Corporation (SMEC).

This report examines the impacts of entrance management, rural drainage strategies, and SEPP14 wetland protection. 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 and its catchment. Key conclusions from this analysis are summarised below.

Entrance Management

With increases in the m AHD at which the ICOLL is opened (natural or artificial), there is an increase in lake and flood levels and consequently the inundation of urban property, farmland, sand and mud flats and melaleuca forests. These increases in the inundation of urban property and farmland lead to a very small to small increase in community costs. Entrance management scenarios did not impact water quality inputs to the ICOLL other than ASS inputs, although with flushing TSS concentrations do show changes with the 1.2 m AHD and natural opening regime options. Permanently opening the ICOLL has mixed impacts on estuary water quality. These changes to estuary water quality and inundation in turn have mixed impacts on aquatic and terrestrial ecological values. However, all scenario options suggest a very small to small increase in the vulnerability of migratory bird populations, reflecting increased inundation of mud and sand flats and melaleuca forest. The entrance management runs illustrate the complexity of the Belongil system, showing that the different entrance management strategies have quite varied and complex impacts on terrestrial and aquatic ecology of the ICOLL and its catchment. They reflect the impacts of entrance management on lake water level and flushing and consequent effects on inundation and estuary water quality. All options lead to negative consequences in some values and positive effects on others. No option is preferable in all impacts. Thus the decision to change the entrance management strategy for Belongil Creek needs to consider fairly complex trade-offs.

Rural Drainage

Rural drainage options have a range of impacts. Installing WCS at Ewingsdale Rd reduced ASS inputs to the ICOLL, reducing Al, Fe and increasing pH. The Decouple Cumbebin Swamp option was the least effective of all drainage options at reducing ASS inputs to the lake. Decoupling Belongil generally has ecological benefits with only minor negative impacts for a few nodes. This option has significant benefits in terms of decreasing fish kills. While not as effective as implementing all drainage options (with and without a permanently open entrance), this may be a relatively low cost option for the level of impact it achieves. Implementing all drainage options generally shows a cumulative impact, such that there are moderate to large impacts in lake flushing, ASS inputs, saltmarsh, pH, farmland inundation, Al, Fe, DO, black water inputs, decouple hydrology and fish mobility. The last two options considered were the combinations of all rural drainage options with the extreme entrance management options: no artificial opening and maintaining the entrance opening. The drainage options scenario and entrance management combinations show mixed impacts across all nodes in the Belongil CLAM and illustrate the complexities of the Belongil system and the difficulties of identifying impacts of combined management options. Drainage options and a permanently open entrance have clear benefits in terms of ASS inputs, pH in the ICOLL and fish kills. However, these benefits may be at the expense of other ecological or social values in the ICOLL and its catchment.

SEPP14 Wetland protection

The best outcome for wetlands in the Belongil Creek catchment would be the protection of all wetlands followed by buy back of privately owned wetlands. Currently, this node is not linked to other variables (e.g. wetland fauna). Future updates of the Belongil CLAM should consider adding this link and others to demonstrate other possible benefits of wetland protection.

1 INTRODUCTION

This Sustainability Assessment report is based on results from the Coastal Lake Assessment and Management (CLAM) tool for Belongil 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 Belongil 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 as well as fishing and aquacultural activities. Remediation of impacts through better controls on developments, replanting of riparian areas and remediation of fringing wetlands, as well as controls on activities directly affecting estuaries such as boating, fishing and recreation are also frequently being considered by State and Local authorities. The CLAM has been developed to show the multitude of impacts arising from such pressures and potential remediation measures. It is most appropriate for strategic planning purposes such as the development of estuary management plans or in other planning activities where a high level of community participation is desirable and an open and transparent modelling tool, which provides full detail of assumptions made and data used in its population, can be of assistance.

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

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

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

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

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

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

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

2 BELONGIL CLAM

2.1 Conceptual framework

The Belongil 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 lake level and water quality parameters such as total suspended sediment, which in turn depend on actions including climate change, urban development, and the management of the ICOLL's entrance. Definitions of all nodes in this framework are provided in Appendix 1.

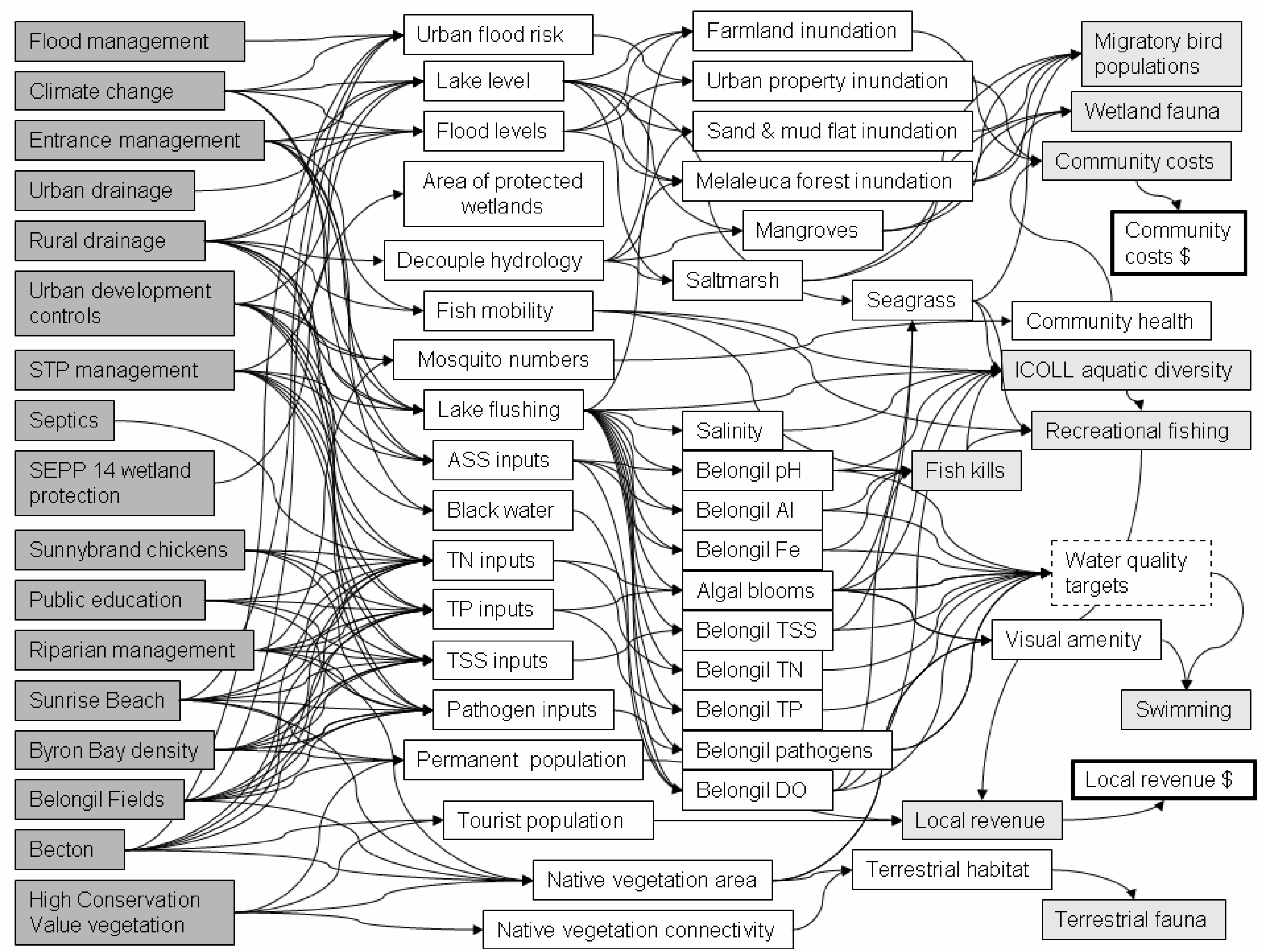

Figure 1. Belongil Creek conceptual framework

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 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 Belongil Creek is then given. This statement was provided by Jennita Gay and Angus Ferguson who put together the data for the Belongil CLAM.

Table 1 provides a qualitative assessment of data quality for each node in the Belongil CLAM. A description of each node is provided in Appendix 1.

Table 1. Data quality in the Belongil CLAM

Node	Quality of Data	Reason	Suggested improvements
Algal Blooms	Very Good	Empirical model based on measured chlorophyll data.	Expert review of data
Area of protected wetlands	Excellent	GIS interpretation of wetland areas protected under legislation	Expert review of results
ASS inputs	Good	Based on Belongil ICOLL water balance model verified against measured pH data.	Current model basic representation and could be strengthened incorporating groundwater flows and tidal pumping and calibrated to field observations.
Belongil Al	Average	Assumptions based on limited Al data and simple empirical model	More comprehensive event sampling for metals. Better hydrodynamic, flushing time and salinity models
Belongil DO	Good	Based on Belongil ICOLL 1-D salt balance box model verified with measured DO data (11 runoff events)	Currently only verified for runoff events. No data on DO dynamics during low to median flow conditions
Belongil Fe	Average	Assumptions based on limited measured Fe data and simple empirical model	More comprehensive event sampling for metals. Better hydrodynamic, flushing time and salinity models
Belongil pathogens	Good	Based on Belongil ICOLL box model verified with measured measured faecal coliform concentrations	Measured concentrations highly variable. Model improved through inclusion of better spatial resolution, decay constants, catchment runoff and flushing models and better catchment pathogen export model.

Belongil pH	Very good	Based on Belongil ICOLL 1-D salt balance box model and ASS inputs verified with measured pH data	The good fit between measured and predicted pH values (Figure 1) gives confidence in the simple modeling approach used. Further improvement under drier conditions would improve model performance.
Belongil TN	Very good	Based on Belongil ICOLL 1-D salt balance box model and verified with measured TN data	Good fit between measured and modelled TN. Better runoff and flushing models would improve estimates as would better catchment TN export model.
Belongil TP	Very good	Based on Belongil ICOLL 1-D salt balance box model and verified with measured TP data	Good fit between measured and modelled TP. Better runoff and flushing models would improve estimates as would better catchment TP export model.
Belongil TSS	Very good	Based on Belongil ICOLL 1-D salt balance box model and verified with measured TSS data	Good fit between measured and modelled TSS. Better runoff and flushing models would improve estimates as would better catchment TSS export model.
Black water inputs	Average	Based on simple model and assumptions with no calibration/verification	Model can be improved by utilising results from flood modelling currently being undertaken (MIKE21).
Community costs	poor	Derived from assumptions no local data or verification	Requires expert opinion or validation data for Belongil.
Community health	poor	Derived from assumptions no local data or verification	Requires expert opinion or validation data for Belongil.
Decouple hydrology	Excellent	Derived from orthophoto interpretation and in consultation with stakeholders	none (subject to review)
Farmland inundation	Good	Derived from orthophoto interpretation	Ground-truthing of rural landuse areas below 2m contour and susceptibility to inundation would improve accuracy. Use of the MIKE21 model currently under development would also improve results.
Fish kills	Poor	Literature review, assumptions and expert opinion	Highly complex issue and reliant on a large number of factors. Difficult to improve on current approach.
Fish mobility	Poor	Based on assumptions and expert opinion	More specific analysis of the requirements of individual species common to the Belongil ICOLL would improve this analysis.
Flood levels	Average	Based on assumptions and expert opinion	Analysis would be improved with a MIKE21 flood model for the Belongil catchment

ICOLL aquatic diversity	Average	Based on assumptions and expert opinion	More specific analysis of foodweb structure and key environmental factors. Clear management goals (goal to maintain unique attributes or more diversity)
Lake flushing	Good	Model simulation, expert opinion and data interpretation (existing studies and monitoring [salinity]).	Model verification with local data. Improved water balance model and better description of behaviour when ICOLL is closed.
Lake level	Average	Based on assumptions and expert opinion	Better estimates of the influence of STP effluent and climate change on the water balance in the Belongil ICOLL are needed.
Local revenue	Poor	Based on assumptions	Requires expert review and data for local revenue from a range of sources impacted by the management scenarios.
Mangroves	Good	Based on orthophoto interpretation and supported assumptions	Requires review by specialist mangrove ecologist.
Melaleuca forest inundation	Average	Based on orthophoto interpretation and assumptions	Requires a more detailed DEM, improved flood model and ground-truthing of swamp forest communities.
Migratory bird populations	Poor	Based on assumptions and combination model	Requires local information on the number of migratory birds using the creek and its catchment and review from local experts.
Mosquito numbers	Poor	Based on assumptions	Requires input from expert opinion and/or local data.
Native vegetation area	Very good	GIS data interpretation	Better information on riparian vegetation to provide accurate estimate of 50m buffers.
Native vegetation connectivity	Very good	GIS data interpretation	Better information on riparian vegetation to provide accurate estimate of 50m buffers.
Pathogen inputs	Good	Model simulation based on uncalibrated model and local data	More comprehensive local data collection, detailed expert review and analysis as well as by implementation of the more comprehensive model.
Permanent population	Poor	Based on assumptions	Needs to be updated with currently available data
Recreational fishing	Average	Based on assumptions and expert opinion	Analysis of habitat requirements of key recreational fishing species
Salinity	Good	Based on empirical model simulation using local salinity data (three sites).	Further development of model describing relationship between catchment hydrology, ICOLL flushing times and salinity.
Saltmarsh	Good	Based on data interpretation and expert opinion	Based on general principles not tested in Belongil. Local data would strengthen the assessment.

Sand mud flat inundation	Good	Based on assumptions and orthophoto interpretation	Groundtruthing to support interpretation and a more detailed DEM and MIKE21 flood model would improve the estimations.
Seagrass	Poor	Based on unsupported assumptions and combination model	Expert review of assumptions and results
Swimming	Poor	Based on unsupported assumptions and combination model	Review by local experts and on the behaviour of recreational swimmers in Belongil Creek
Terrestrial fauna	Poor	Based on assumptions	Requires expert opinion, relevant local data and/or literature review to update this node.
Terrestrial habitat	Poor	Based on assumptions	Requires expert opinion, relevant local data and/or literature review to update this node.
TN inputs	Average	Based on uncalibrated model simulation) and data interpretation	Data gaps include: septic tank numbers and positions, Sunnybrand chicken inputs, potential impacts of new developments and urban development controls, and area of access of livestock to the ICOLL.
Tourist population	Poor	Based on assumptions	Requires expert review and/or data collection related tourist populations and behaviour
TP inputs	Average	Based on uncalibrated model simulation) and data interpretation	Data gaps include: septic tank numbers and positions, Sunnybrand chicken inputs, potential impacts of new developments and urban development controls, and area of access of livestock to the ICOLL.
TSS inputs	Average	Based on uncalibrated model simulation) and data interpretation	Data gaps include: potential impacts of new developments and urban development controls. Further information on riparian buffers is also required.
Urban flood risk	Poor	Based on assumptions	The data used to populate this node is considered weak. This is due to known inaccuracies within the Draft Belongil Flood Study, and uncertainty of the areas of potential development, particularly within the Becton development.
Urban property inundation	Good	Based on assumptions and orthophoto interpretation	The use of the MIKE21 flood model developed for the Belongil catchment would also greatly improve estimation of inundation patterns for different management scenarios.
Visual amenity	Poor	Based on assumptions and model simulation	Improved using local information on peoples perceptions of water quality, native vegetation and impacts on visual amenity. Should be reviewed by local experts.
Wetland fauna	Poor	Based on assumptions and model simulation	Improved using local information on wetland fauna communities and their relationships with local flora. Should be reviewed by local experts.

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.
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 Jennita Gay and Angus Ferguson are:

- There is a need for an improved hydrological model of the Belongil system that takes into account groundwater storage and gives better predictions of surface runoff. A model has been developed but has not yet been verified or calibrated with field data;
- Monitoring of inundation patterns of low-lying land; and,
- Application of a flood model of the system that would allow the impact of scenarios included in Belongil CLAM on black water and acid sulphate soil (ASS) inputs to be better captured. A flood model is currently being developed by the Snowy Mountains Engineering Corporation (SMEC).

3 SCENARIOS

In order to develop this Sustainability Assessment analysis a relatively small subgroup of scenarios were selected from the 1,045,094,400 available in the Belongil CLAM. In was decided to focus on the following scenarios:

- Entrance management
- Rural drainage and entrance management
- SEPP14 wetland protection

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

Belongil Creek is periodically open or closed to the ocean, and as such, is regarded as an 'Intermittently closed and opened lake/lagoon'(ICOLL). The tidal prism of the Belongil Creek is too small relative to the littoral sand supply to maintain an open entrance for periods longer than a few days to weeks (Geomarine, 1997). The entrance barrier may be breached due to a combination of beach scour by ocean waves and increased head difference between the ICOLL and the ocean during major rainfall events, or overtopped in the case of large flood events.

Agricultural lands as well as residential and commercial development in the low lying swampy areas of the catchment, including areas within Byron Bay and the Industrial Estate, are prone to flooding when the entrance to Belongil Creek is closed, as the swamplands retain surface water during and after rainfall events. Flood mitigation practices in the catchment have included drainage of wetland areas through constructed channels, and artificially opening the entrance to allow wetland surface waters to escape to the ocean.

Entrance management practices: Initially artificial openings were carried out by landowners who hand dug channels when water levels had encroached on grazing lands. For at least the previous 47 years council has opened the estuary mechanically. Until recently artificial openings were initiated when the water level at the Ewingsdale Road bridge gauge reached 1.2m Australian Height Datum (AHD). Since 2001 the water level trigger for artificially opening the estuary was dropped to 1m AHD following a recommendation to attempt to reduce turbidity observed in the estuary following artificial opening, through reduction of the water velocity of the exiting water.

Maintenance of an open entrance: Recently, entrance management practices have attempted to maintain an open entrance for as long as possible after artificial opening in order to maximise tidal influence in the Belongil ICOLL. This has been done to allow greater tidal flushing of pollutants and to promote shifts toward a more diverse estuarine ecology.

Natural entrance openings: The frequency of natural entrance opening for current drained system is unknown. It is likely that entrance openings would have occurred less frequently at a higher water level under pre European backswamp hydrology than under the current artificially drained system. Natural entrance opening would occur over a range of water levels (termed the "natural breakout range") depending on ocean conditions, antecedent conditions and rainfall patterns across the catchment. The size of the head difference and the ocean conditions (level and wave energy) at the time of breakout will determine the width and depth of the scour channel.

It has been estimated that the upper threshold for breakouts to occur is approximately 2.6m AHD as this represents the overtopping of the mean height beach berm in the area (PWD, 1986; Geomarine, 1997). It is likely that this represents the upper end of the natural breakout range, as other factors such as ocean scour will cause breakouts at lower levels. For the purposes of this CLAM it is assumed that the mode of the natural breakout range is approximately 2m AHD.

This scenario allows for the assessment of the possible impacts of different entrance management strategies for Belongil Creek.

The scenario options are:
1. No change (1m AHD at Ewingsdale Road bridge gauge)
2. Artificially open entrance at 1.2 m AHD
3. No artificial opening of entrance
4. Maintain entrance open

REFERENCES:
Geomarine (1997). Belongil Creek estuary processes study. Belongil Creek estuarine mangagement committee, Byron Shire Council.

Public Works, NSW Department of, (Civil engineering division) (PWD), (1986). Belongil Creek flood study. Report No. L.I.107

3.2 Rural Drainage

The Belongil ICOLL catchment is characterised by extensive low-lying backswamps and barrier dune systems fringed by relatively low relief uplands. There is a lack of distinct natural watercourses and associated distributary levees that commonly separate larger watercourses and backswamp areas (BASSWG, 2004). Under natural conditions freshwater runoff from uplands and direct rainfall moved through the backswamp areas as a combination of gradual groundwater flow and limited surface runoff via indistinct meandering channels. Runoff to the ICOLL also historically occurred from the northwest via inter-dunal channels, however this flow path has been effectively blocked by the industrial estate.

Prior to drainage and artificial opening of the entrance, seasonal ponding of water (to 0.5m) would have occurred over large areas of the backswamp and inter-dunal swales, with inundation periods determined by various factors including rainfall patterns, evapotranspiration, evaporation and estuary entrance conditions. The lack of distributary levees results in a close connectivity between estuarine and freshwater swamp hydrology (BASSWG, 2004), however the low relief of the backswamp catchment means that mass exchange of water between different backswamp areas and the estuary may have been relatively minor while the estuary entrance remained closed.

The Belongil ICOLL catchment has been extensively drained for flood mitigation and agricultural purposes since European settlement, although no major rural drainage works have been undertaken in the past 50 years (Draper, 2002). Artificial drainage of backswamp areas in the Belongil-Cumbebin system has increased the hydrologic connectivity between the swamp and the ICOLL, resulting in a net lowering of ground and surface water levels (Talau, 2002). Surface drains also reduce the time and spatial extent of ponding in the backswamps during the wet season, by increasing the hydraulic potential to transport water to the ICOLL.

The negative impacts of rural drainage include:

- Lowering of water tables in acid sulfate soil (ASS) areas, thereby promoting oxidation of ASS, acid production, and mobilisation of dissolved metals.
- More efficient transport of pollutants such as effluent, ASS runoff and deoxygenated swamp water to the ICOLL.
- Increased tidal inundation of rural lands
- Shifts in endangered ICOLL wetland communities towards estuarine ecology and the conversion of open backswamps to dryland pastures and Melaleuca forests

Recent management initiatives are investigating various modifications to the drainage network aimed at addressing negative impacts by “decoupling” the backswamp areas from the ICOLL. This scenario includes short-listed options developed in consultation with stakeholders including the Belongil Drainage Board, Byron Shire Council, NSW Department of Natural Resources, NSW Department of Agriculture, and community representatives. The options are:

1. No change – do nothing to the existing drainage network
2. Water control structures (WCS) at Ewingsdale Rd + ICOLL head – The purposes of these WCS are 1) to exclude tidal influence throughout the Belongil Swamp drainage network, and 2) to maintain minimum drainage levels in this area to just below ground level.
3. WCS at Skinners Shoot – This involves WCS at the two culverts under Skinners Shoot Rd in order to decouple the Cumbebin Swamp system from the ICOLL. The purpose is to restore more natural drainage to this SEPP14 area and reduce the drainage of ponded flood waters in the event of an entrance opening.
4. Decouple Belongil swamp – Involves WCS on the main outlets of the levee separating the Union Drain from the SEPP14 Belongil Swamp. The purposes are to 1) maintain higher water tables and reduce ASS runoff; 2) restore more natural hydrology; and 3) to reduce the discharge of deoxygenated swamp water to the ICOLL.
5. Fill in Fletchers drains – Involves the infill of surface feeder drains in agricultural lands to the south of Belongil Swamp. The purposes are to 1) exclude tidal influence throughout the Belongil Swamp drainage network, and 2) to maintain minimum drainage levels in this area to just below ground level.
6. All of the above – do all of the above options together.

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The Belongil Acid Sulfate Soils Working Group (BASSWG) (2004). Belongil swamp acid sulfate soils remediation concept plan. DIPNR & Byron Shire Council.

Draper, C. (2002) Towards a Belongil Management Plan. Paper presented to 'Belongil Wetland – where to from here?: Background Papers to Current Management Issues'. Ewingsdale Hall, 4 November 2002.

Tulau, M.J. (2002) Towards a Belongil Management Plan. Paper presented to 'Belongil Wetland – where to from here?: Background Papers to Current Management Issues'. Ewingsdale Hall, 4 November 2002.

3.3 SEPP14 wetland protection

This scenario currently facilitates assessment of the change in area of wetlands associated with management options.

The data used was extracted from GIS layers provided by Byron Shire Council (BSC), The Department of Natural Resources (DNR), The Department of Environmental Conservation (DEC) and WetlandCare Australia (WCA) by Cassie Burns from WetlandCare Australia.

The current options are:
1. No change
2. Buy back SEPP14 on private land
3. Protect all wetlands

4 RESULTS FROM SCENARIO RUNS

4.1 Entrance management

Four entrance management options were considered including the 'do nothing' option. It should be noted that impacts are described relative to the base case such that an "increase" is a greater probability of a higher value option. So for example if a node was likely to decrease in value under the base case, "increase" in the table below implies that the node will have a higher probability of a greater value. This might still mean that that the node will decrease but may not decrease by as great an amount as the base case or it may indicate that the node will in fact increase. These options had no impact on 17 nodes: Area of protected wetland; TN inputs; Permanent population; Native vegetation area; Urban flood risk; Terrestrial habitat; Mosquito numbers; Native vegetation connectivity; Tourist population; Community health; Terrestrial fauna; TP inputs; TSS inputs; Pathogen inputs; Decouple hydrology; Swimming; Visual amenity. Impacts on other nodes are summarised in Table 2.

Table 2. Summary of impacts of entrance management

	Open at 1.2m AHD	No artificial opening	Maintain entrance open
Urban property inundation	Very small increase	Small increase	No impact
Lake level	Moderate increase	Small to moderate increase	Small to moderate decrease
Flood levels	Small increase	Moderate increase	Very small decrease
Lake flushing	Small increase	Moderate increase	Small decrease
ASS inputs	Very small decrease	Moderate to large decrease	Very small increase

Sand mud flat inundation	Small increase	Small increase	Very small decrease
Melaleuca forest inundation	Small increase	Moderate increase	Very small decrease
Seagrass	Very small decrease	Moderate decrease	Moderate increase
Recreational fishing	Very small decrease	Small decrease	Small increase
ICOLL aquatic diversity	Very small decrease	Small decrease	Small increase
Mangroves	Very small decrease	Very small decrease	No impact
Saltmarsh	Small increase	Small increase	Small decrease
Belongil pH	Very small increase	Moderate increase	No impact
Community costs	Very small increase	Small increase	No impact
Algal blooms	No impact	Moderate decrease	Small increase
Fish kills	Very small increase	Moderate increase	Very small decrease
Migratory bird populations	Very small increase	Small increase	Very small increase
Wetland fauna	Small decrease	Moderate decrease	Very small increase
Farmland inundation	Very small increase	Small increase	Very small decrease
Local revenue	No impact	Very small decrease	Very small increase
Belongil Al	No impact	Moderate decrease	Very small increase
Belongil Fe	No impact	Moderate decrease	Very small decrease
Belongil TSS	Very small increase	Moderate increase	Small decrease
Belongil TN	No impact	Moderate decrease	Very small increase in extremes
Belongil TP	No impact	Moderate decrease	No impact
Belongil pathogens	No impact	Small to moderate decrease	No impact
Belongil DO	Very small decrease	Moderate decrease	Very small increase
Black water inputs	Small decrease	Very large decrease	Small increase
Fish mobility	Moderate decrease	Very large decrease	Moderate increase
Salinity	Very small increase	Moderate increase	Small decrease

Entrance management is assumed, together with climate change, to control the mean ICOLL water level which influences the head potential for the drainage of acid groundwater to the drainage network. Table 2 shows that opening the ICOLL entrance at 1.2 m AHD results in a very small decrease in acid sulphate soil (ASS) inputs while returning the system to its natural opening regime moderately decreases ASS inputs to the ICOLL. Permanently opening the entrance may lead to a small increase in ASS inputs although pH in the ICOLL does not change due to decreased flushing (defined as the freshwater replacement time). When the entrance opening height is increased (options 2 and 3) changes to the pH of the ICOLL match the change in ASS input. These scenarios do not impact other water quality inputs to the ICOLL although with changes to flushing Al, Fe, TN, TP and pathogen concentrations show no impact to the 1.2 m AHD option and moderate decreases with a return to the natural opening regime. In contrast, TSS concentrations show a very small and moderate increase with the 1.2 m AHD and natural opening regime options, respectively. The impacts of permanently opening the ICOLL are mixed with no impact on pathogens and TP, very small increases in Al, very small decreases in Fe and TSS, and very small increases in extreme TN concentrations. Belongil DO is impacted by blackwater inputs and flushing, with dilution mitigating the effect of very large decrease in blackwater inputs with a return to a natural opening regime.

With increased height in m AHD at which the ICOLL is opened (natural or artificial), there is an increase in lake and flood levels and consequently the inundation of urban property, farmland, sand and mud flats and melaleuca forests. These increases in the inundation of urban property and farmland lead to a very small to small increase in community costs. The small decrease in farmland inundation with a permanently opened entrance has no discernible impact on community costs.

Changes to the water quality in the estuary and inundation values have mixed impacts on aquatic and terrestrial ecological values. Opening the ICOLL at 1.2 m AHD led to a very small decrease in seagrass and mangroves, a small decrease in the vulnerability of wetland fauna, a moderate decrease in fish mobility, a very small increase in fish kills and a small increase in saltmarsh. Similar trends, albeit with larger impacts, exist under a natural opening regime. The exception to this is for algal blooms where no impact is seen for 1.2 m AHD and moderate decreases with a return to a natural opening regime. Permanently opening the ICOLL's entrance may lead to a small decrease in recreational fishing and algal blooms and a small decrease in saltmarsh. All scenario options suggest a very small to small increase in the vulnerability of migratory bird populations, reflecting increased inundation of mud and sand flats and melaleuca forest with 1.2 m AHD and natural opening regimes and mixed impacts on seagrass, saltmarsh and mangroves with a permanently opened entrance.

Figure 2 shows the impact of entrance management on TSS concentrations in the estuary in more detail.

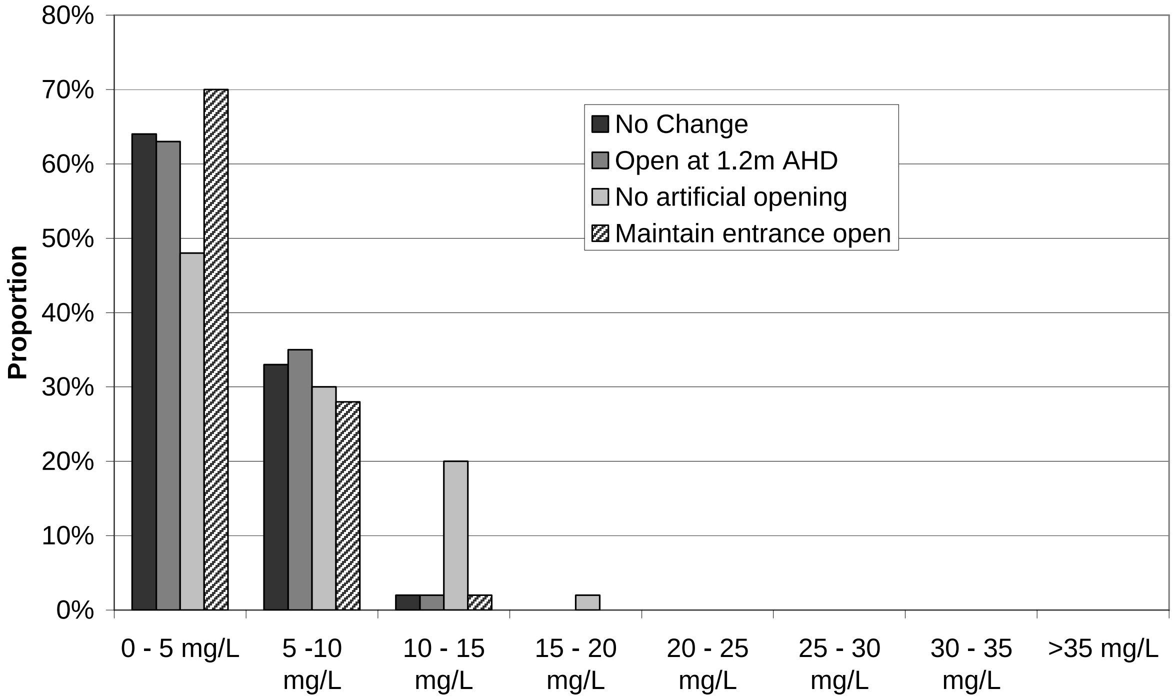

Figure 2. Impact of entrance opening on Belongil TSS

For all options, the most likely concentration is 0-5 mg/L (Figure 2). Opening the ICOLL at 1.2 m AHD has only a small impact with a 2% increase in the probability of concentrations between 5-10 mg/L. With a return to a natural opening regime there is a large shift in TSS concentration with a 20% chance of 10-15 mg/L and less than 50% chance of current (no change) concentrations of 0-5 mg/L. Maintaining the entrance open is likely to reduce TSS concentrations with a 70% change of 0-5 mg/L.

In Figure 3, chlorophyll-*a* concentrations largely fall within the 5-10 mg/L and 10-15 mg/L ranges. Increasing the entrance opening height to 1.2 m AHD has no impact on chlorophyll-*a* concentrations. Reverting to a natural opening regime increases the chance of the lowest concentration range (0-5mg/L) from 7% to 27% reflecting reduced N loading associated with a 25% change of the freshwater replacement time (flushing) exceeding 30 days.

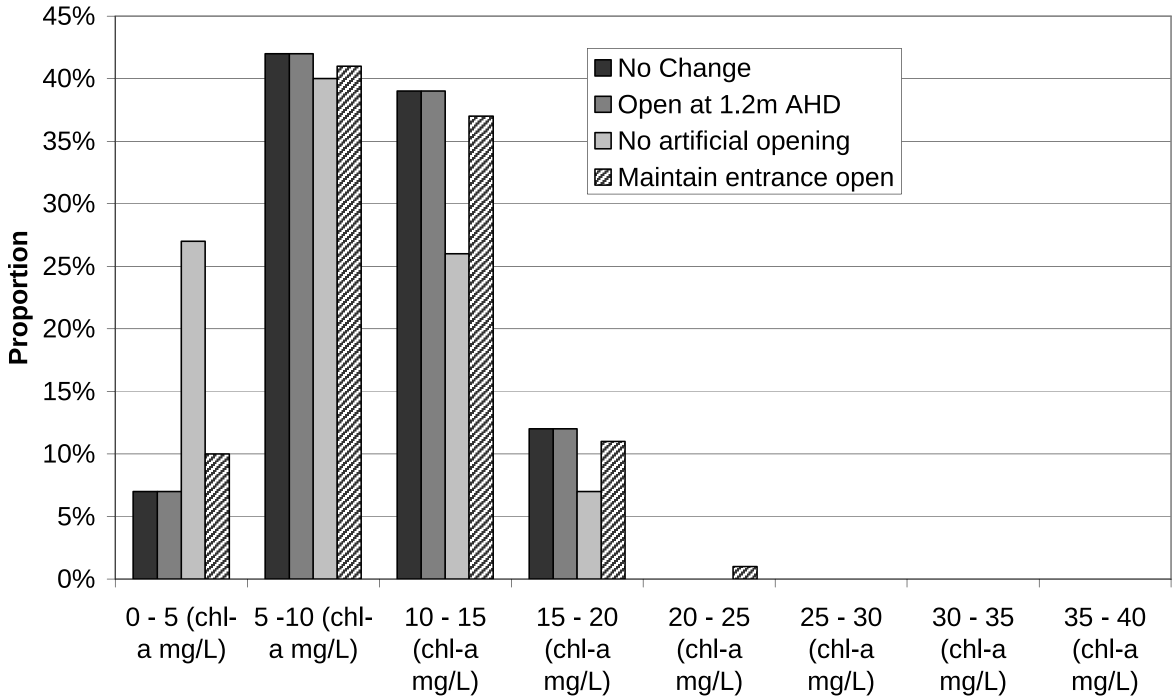

Figure 3. Impact of entrance opening on Algal Blooms

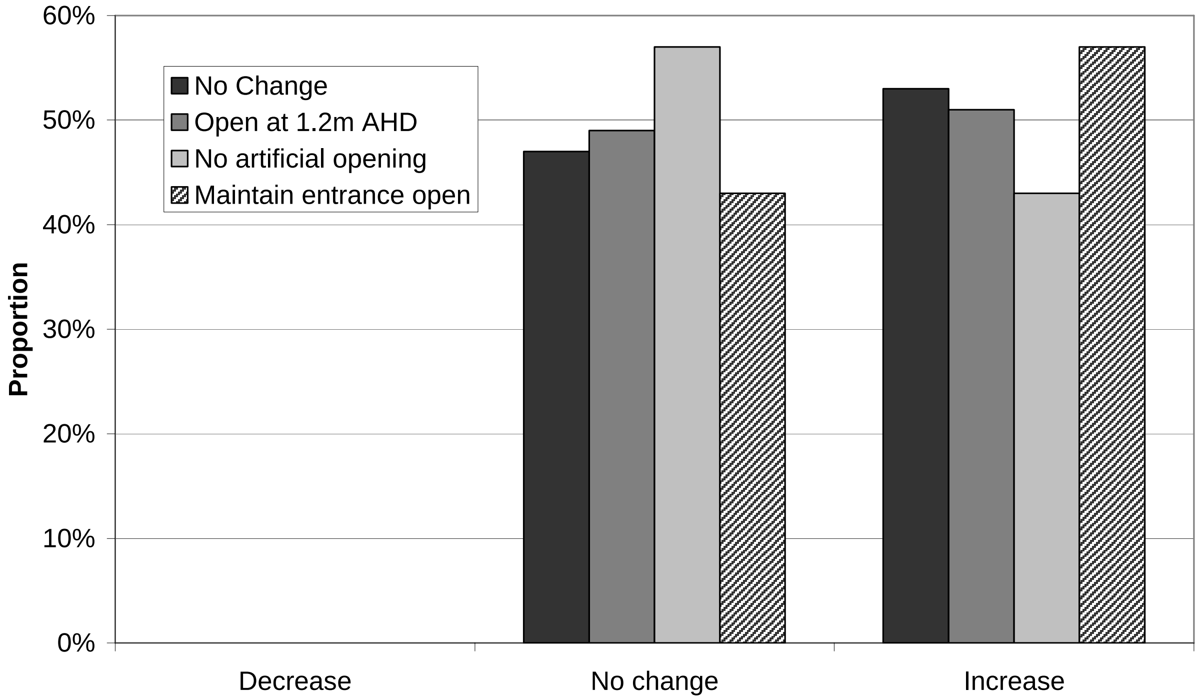

Figure 4. Impact of entrance opening on Seagrass

While there are currently no seagrass communities in Belongil there has been in the past. Increasing the height at which the ICOLL is opened reduces the likelihood of an increase in conditions conducive to seagrass recolonisation (Figure 4). Interestingly, the greatest differences in outcomes occurs when reverting back to natural conditions, where the probability for improved conditions for recolonisation drops from 53% (no change) to 43%.

However, there is considerable uncertainty in this node, as evidenced by the relatively even spread between the No Change and Increase output states.

Overall these results show that the different entrance management strategies have quite varied and complex impacts on terrestrial and aquatic ecology of the ICOLL and its catchment. This reflects the impacts of entrance management on lake water level and flushing and consequent effects on inundation and estuary water quality. All options are likely to lead to negative consequences in some values and positive effects on others. Thus the decision to change the entrance management strategy for Belongil Creek needs to consider fairly complex trade-offs and no option is preferable in all impacts.

4.2 Rural drainage and entrance management

The rural drainage and entrance management options were run in combination, giving a total of 8 scenarios including the “No change” option. Table 3 provides a summary of impacts on all nodes for which there was an impact of these scenarios. These scenarios have no impact on 12 nodes: Area of protected wetland, TN inputs, Permanent population, Native vegetation area, Urban flood risk, Terrestrial habitat, Native vegetation connectivity, Tourist population, Terrestrial fauna, TP inputs, TSS inputs, Pathogen inputs.

Table 3 summarises the impact of these options on all other nodes in the framework. This table shows that there are no individual impacts of any drainage option on urban property inundation, lake levels and mangroves. Installing WCS at Ewingsdale Rd and the ICOLL head does not impact lake or flood levels, lake flushing, or inundation values with the exception of very small increases in melaleuca forests and a moderate decrease in farmland inundation. The WCS’s generally did not impact water quality inputs and concentrations in the ICOLL with the exception of a moderate decrease in Al and Fe, large decreases in ASS inputs and small to moderate increases in pH. This leads to a small decrease in fish kills although the moderate decrease in fish mobility with the WCS’s in place negates the reduction in fish kills in terms of the health of fish populations. Consequently, we see a very small decrease in ICOLL aquatic diversity. The WCS’s act to significantly increase the amount of land below 1.2 m AHD with hydrology decoupled from estuarine influence (decouple hydrology). This has mixed flow-on effects on estuarine ecology with moderate increases in saltmarsh and a very small increase in melaleuca forest inundation. Overall the WSC leads to a very small decrease in the vulnerability of migratory bird populations and small to moderate decreases in the vulnerability of wetland fauna.

The Decouple Cumbebin Swamp and Decouple Belongil Swamp options have similar impacts on CLAM nodes, although the impacts from the Decouple Belongil Swamp option are general larger (Table 3). Both options show a very small decrease in flood levels and sand mud flat inundation. Decoupling Cumbebin shows small decreases in farmland inundation compared with moderate decreases for decoupling Belongil. Lake flushing shows a small to moderate increase (Cumbebin) and moderate increase (Belongil). These changes do not greatly impact water quality in the ICOLL when decoupling Cumbebin, with only very small increases in TSS and DO concentrations. By decoupling Belongil swamp, we see very small to small increases in Al, Fe, TSS, TN and TP concentrations, moderate increases in Belongil DO, and moderate to large increases in black water inputs. Neither decoupling scenario impacts Belongil pathogens. Decoupling these swamps improves fish mobility leading to a very small to small decrease in fish kills. Decoupling Belongil generally has ecological benefits with increases in saltmarsh, ICOLL aquatic diversity, decreased vulnerability of wetland fauna, and decreases in algal blooms. Negative impacts are a small decrease in seagrass beds, a small increase in melaleuca forest inundation and a very small increase in the vulnerability of migratory bird populations as well as a small increase in mosquito populations.

Table 3. Summary of impacts of rural drainage and entrance management

	WCS at Ewingsdale Rd + Est. head	Decouple Cumbebin swamp	Decouple Belongil swamp	Fill in Fletchers drains	All drainage options	No artificial opening and all drainage options	Maintain entrance open and all drainage options
Urban property inundation	No impact	No impact	No impact	No impact	No impact	Very small increase	No impact
Lake level	No impact	No impact	No impact	No impact	No impact	Small to moderate increase	Moderate decrease
Flood levels	No impact	Very small decrease	Very small decrease	No impact	Small decrease	Moderate increase	Small decrease
Lake flushing	No impact	Small to moderate increase	Moderate increase	No impact	Moderate increase	Very large increase	Large increase
ASS inputs	Large decrease	No impact	Very small decrease	Very small decrease	Large decrease	Large decrease	Large decrease
Sand mud flat inundation	No impact	Very small decrease	Very small decrease	No impact	Very small increase	Very small increase	Very small decrease
Melaleuca forest inundation	Very small increase	Uncertain impact	Small increase	Very small increase	Uncertain impact	Small increase	Very small decrease
Seagrass	No impact	Very small decrease	Small decrease	No impact	Small decrease	Moderate decrease	Small decrease
Recreational fishing	Very small increase	Small increase	Small increase	No impact	Small increase	Small decrease	Small to moderate increase
ICOLL aquatic diversity	Very small decrease	Very small increase	Small increase	No impact	Very small increase	Small to moderate decrease	Small to moderate increase
Mangroves	No impact	No impact	No impact	No impact	No impact	Very small decrease	No impact

Saltmarsh	Moderate increase	Small increase	Small to moderate increase	Small increase	Moderate increase	Moderate to large increase	Moderate increase
Belongil pH	Small to moderate increase	No impact	Very small increase	Very small increase	Moderate increase	Moderate to large increase	Moderate increase
Community costs	Small decrease	Very small decrease	Small decrease	Small increase	Increased uncertainty	Increased uncertainty	Increased uncertainty
Algal blooms	No impact	No impact	Small decrease	No impact	Small decrease	Moderate decrease	Small decrease
Fish kills	Small decrease	Very small decrease	Small decrease	No impact	Small to moderate decrease	Increase uncertainty	Moderate decrease
Swimming	No impact	No impact	No impact	No impact	Very small decrease	Very small decrease	Very small decrease
Visual amenity	No impact	No impact	No impact	No impact	Very small decrease	Very small decrease	Very small decrease
Migratory bird populations	Very small decrease	No impact	Very small increase	No impact	Very small decrease	Very small increase	No impact
Wetland fauna	Small to moderate decrease	No impact	Small decrease	No impact	Small to moderate decrease	Moderate decrease	Small decrease
Mosquito numbers	No impact	Small increase	Small increase	Small to moderate decrease	Small to moderate decrease	Small to moderate decrease	Small to moderate decrease
Farmland inundation	Moderate decrease	Small decrease	Moderate decrease	Small decrease	Moderate decrease	Increased uncertainty	Moderate decrease
Community health	No impact	Small increase	Small increase	Small to moderate decrease	Small to moderate decrease	Small to moderate decrease	Small to moderate decrease
Local revenue	No impact	No impact	Very small increase	No impact	Very small increase	Very small decrease	Very small increase
Belongil Al	Moderate decrease	No impact	Small decrease	Very small decrease	Moderate to large decrease	Large decrease	Moderate to large decrease
Belongil Fe	Moderate decrease	No impact	Very small	Very small	Moderate decrease	Moderate	Moderate decrease

			increase	decrease		decrease	
Belongil TSS	No impact	Very small increase	Small increase	No impact	Small increase	Moderate increase	Smalll increase
Belongil TN	No impact	No impact	Very small decrease	No impact	Very small decrease	Small decrease	Very small decrease
Belongil TP	No impact	No impact	Very small decrease	No impact	Very small decrease	Moderate decrease	Very small decrease
Belongil pathogens	No impact	No impact	No impact	No impact	No impact	Moderate decrease	No impact
Belongil DO	No impact	Very small increase	Moderate increase	No impact	Moderate to large increase	Increased uncertainty	Moderate to large increase
Black water inputs	No impact	No impact	Moderate to large increase	No impact	Moderate to large increase	Small decrease	Moderate to large increase
Decouple hydrology	Large increase	Small increase	Moderate increase	Small increase	Large increase	Large increase	Large increase
Fish mobility	Moderate decrease	Moderate increase	Moderate to large increase	Small increase	Moderate increase	Large decrease	Large increase
Salinity	No impact	Very small increase	Small increase	No impact	Small increase	Moderate increase	Small increase

Filling in Fletchers Drain only impacts ASS inputs, melaleuca forest inundation, saltmarsh, Belongil pH, community costs, mosquito numbers, farmland inundation, community health, Belongil Al, BElongil Fe, decouple hydrology and fish mobility, although most impacts are minor (very small to small). Filling in the drain does lead to small to moderate decreases in mosquito numbers and small decreases in farmland inundation.

Implementing all drainage options generally shows a cumulative impact, such that there are moderate to large impacts in lake flushing, ASS inputs, saltmarsh, pH, farmland inundation, Al, Fe, DO, black water inputs, decouple hydrology and fish mobility (Table 3). These cumulative impacts mean that we start to see very small negative impacts on swimming and visual amenity. For visual amenity, small increases in TSS concentrations negate the small decreases in algal blooms. For some nodes, the complex interactions show highly uncertain impacts illustrating the difficulty in estimating the nature of changes associated with a value that depends on a complex set of competing environmental or social outcomes. For both melaleuca forest inundation and community costs, it is difficult to ascertain the direction of change let alone the magnitude of any change.

The last two options considered are the combinations of all rural drainage options with the extreme entrance management options: no artificial opening and maintaining the entrance opening. These scenarios illustrate the complexities of the Belongil system and the difficulties of identifying impacts of combined management options. Where the isolated impacts of all drainage options and the entrance management options had the same direction of change (or where one option had no impact) the impacts are cumulative. For example, all drainage options in combination with no artificial opening provides a very large increase in flushing (freshwater replacement time in days) although each scenario in isolation showed a moderate increase. Interestingly, maintaining the entrance open leads to a small decrease in flushing, although in combination with rural drainage results in a large increase in flushing. Lake levels and flood levels are largely controlled by the entrance management strategy while entrance management strategies in concert with rural drainage have no added impact on swimming, visual amenity, mosquito numbers, community health or decouple hydrology. When the isolated impacts of the differenct scenario options had opposite impacts there is either increased uncertainty in impacts (e.g. fish kills and farmland inundation for the natural opening regime and rural drainage) or a dampening of the dominant scenarios impact (e.g. migratory bird populations for both rural drainage and entrance management options). Consequently the ecological impacts of these scenario combinations are mixed. With a return to a natural opening regime, there are very small to small increases in the inundation of sand mud flats and melaleuca forests, small to moderate decreases in ICOLL aquatic diversity, moderate to large increases in saltmarsh, moderate decreases in the vulnerability of migratory bird populations, a large decrease in fish mobility and a moderate decrease in the vulnerability of wetland fauna. With a permanently opened entrance, there are very small decreases in the inundation of sand mud flats and melaleuca forests, small to moderate increases in ICOLL aquatic diversity, a small decrease in seagrass, moderate increases in saltmarsh, moderate decreases in the vulnerability of migratory bird populations, a large increase in fish mobility and a small increase in the vulnerability of wetland fauna.

Figure 5 shows the impact of rural drainage and entrance management on ASS inputs to the ICOLL in more detail.

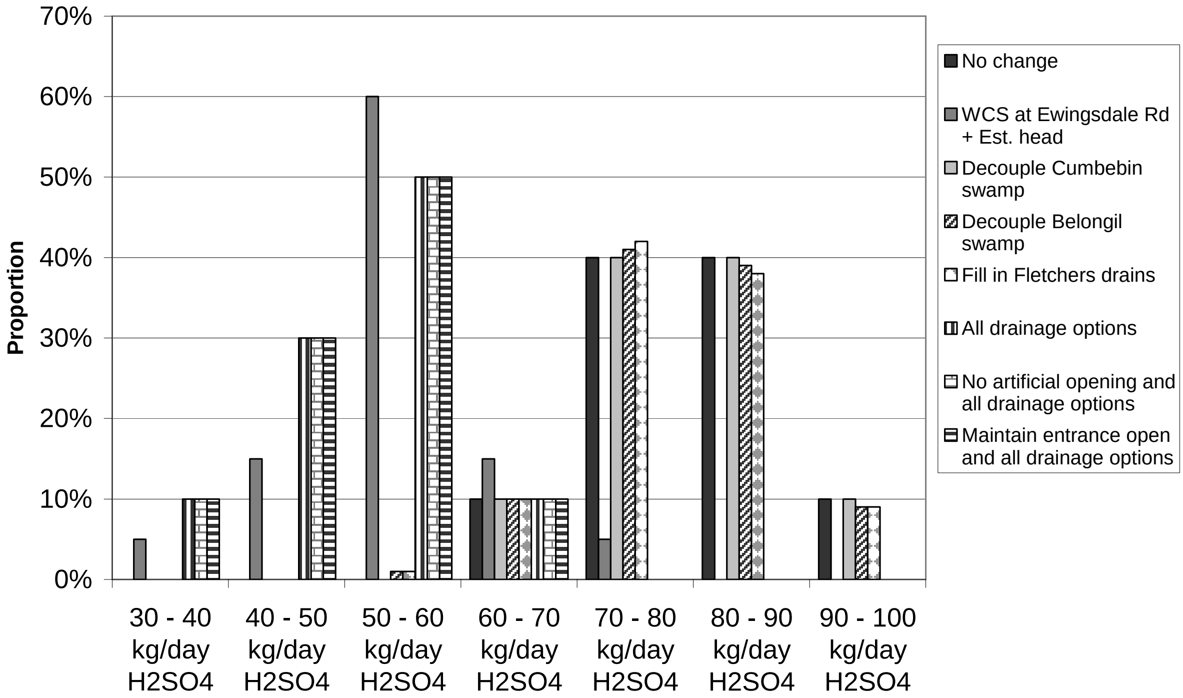

Figure 5. Impacts of rural drainage and entrance management on ASS inputs

For the base (no change) option, ASS inputs are most likely to fall within the 70-80 kg/day H_2SO_4 and 80-90 kg/day H_2SO_4. Decoupling Cumbebin Swamp has no impact on ASS inputs while decoupling Belongil Swamp or filling in Fletchers Drain show minor shifts from the 80-90 kg/day H_2SO_4 to the 70-80 kg/day H_2SO_4 range. Implementing the WCS at Ewingsdale Rd and the ICOLL head shows a 60% chance of ASS inputs being in the range of 50-60 kg/day H_2SO_4. The cumulative impacts of all drainage options further reduce ASS inputs to the ICOLL with an 80% chance that inputs will be between 40-60 kg/day H_2SO_4. The entrance management strategy has no added impacts.

pH levels in the ICOLL (Belongil pH) reflect the combined impact of lake flushing and ASS inputs and show the influence of entrance management in addition to the rural drainage option (Figure 6). Again, decoupling Cumbebin swamp has no impact in Belongil pH. The large decrease in ASS inputs from the WCS option are reflected by a >40% chance of a pH between 5.6 and 5.8 compared with a 15% chance of this range for the no change option. pH is further increased for all drainage options although the impact is not as large as observed for ASS inputs, due largely to dampening effects of lake flushing. The pH of Belongil Creek is highly uncertain for the natural opening regime with all output states having some chance of occurrence. The most likely output state (31%) is the 5.6-5.8 pH range. Maintaining the entrance open and implementing all drainage options has a similar impact to the impact of applying all drainage options, although slightly increases the change of a 5.8-6.0 value. This shift is reflected in a decreased probability of a pH between 5.4 and 5.6. Otherwise all output states have the same probability of occurrence.

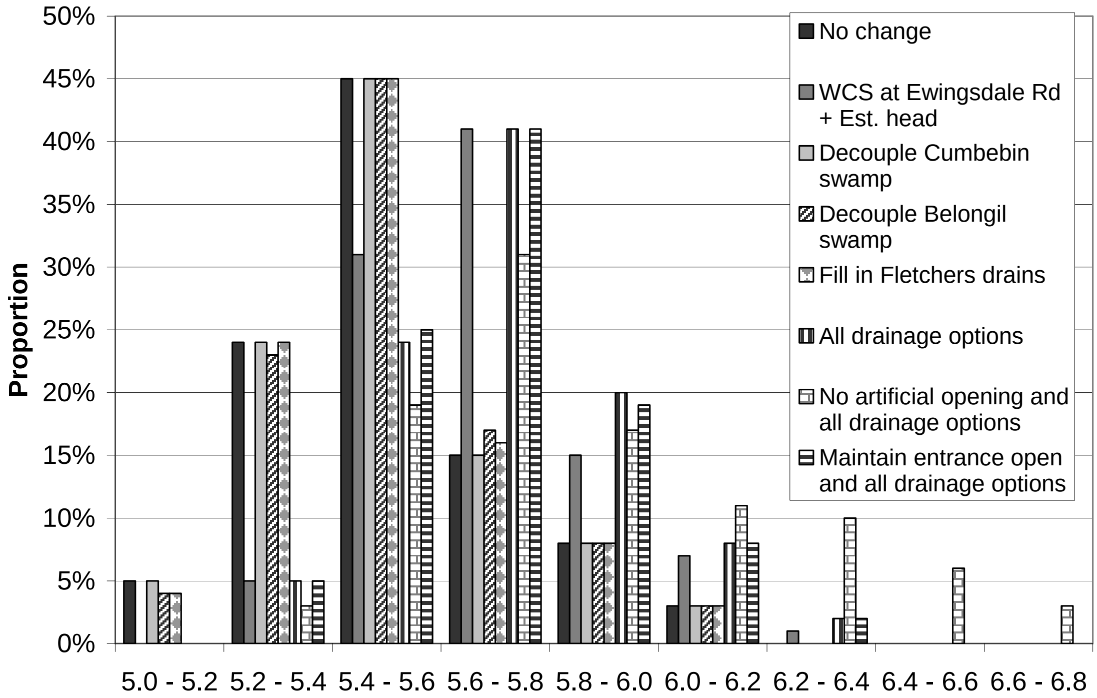

Figure 6. Impacts of rural drainage and entrance management on Belongil pH

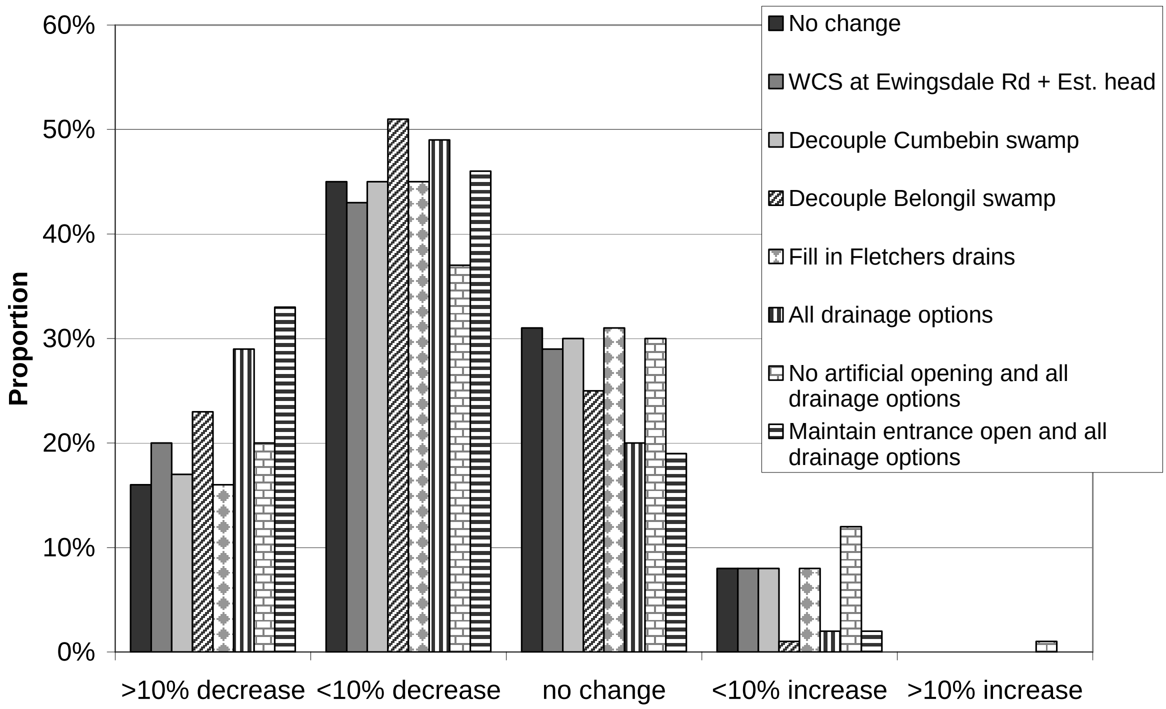

Figure 7. Impacts of rural drainage and entrance management on Fish Kills

Fish kills are impacted by pH and Al, Fe and DO concentrations in the lake as well as fish mobility (Figure 7). All scenarios are most likely to have a <10% decrease in fish kills, ranging from a 37% chance for all drainage options and a natural opening regime to 51% for the decoupling of Belongil Swamp. Decoupling Cumbebin Swamp, while not impacting ASS inputs and Belongil pH, increases fish mobility, and slightly increases the chance of no change in fish kills (shifting from a <10% decrease). The best outcome is achieved by implementing all drainage options and maintaining the entrance open due to increased fish mobility and changes to the flushing regime. By returning the system to its natural opening regime, the chance of a <10% increase in fish kills rises from 8% (no change) to 12% and there is a very slight chance (1%) of a >10% increase in fish kills. Of the individual drainage options, decoupling Belongil swamp has significant benefits in terms decreasing fish kills. While not as effective as implementing all drainage options (with and without a permanently open entrance), this may be a relatively low cost option for the level of impact it achieves.

Overall, the drainage options scenario and entrance management combinations show mixed impacts across all nodes in the Belongil CLAM. Drainage options and a permanently open entrance have clear benefits in terms of ASS inputs, pH in the IOCOLL and fish kills. However, these benefits may be at the expense of other ecological or social values in the ICOLL and its catchment.

4.3 SEPP14 wetland protection

In the Belongil CLAM, the area of protected wetlands is linked to the SEPP14 wetland protection scenario which has 3 options: no change, buy back privately owned wetlands and protection of all wetlands. Currently there are of the order of 500 to 600 hectares of protected wetlands (Figure 8). With buy back of privately owned SEPP14 lands there is a 70% change of 600-700 hectares of protected wetlands. While unlikely, the best outcome for wetlands in the Belongil Creek catchment would be the protection of all wetlands where there is a 95% probability of 1000-1200 hectares of protected wetlands.

Currently, the area of protected wetlands node is not linked to other variables (e.g. wetland fauna). Future updates of the Belongil CLAM should consider adding this link and others to demonstrate other possible benefits of wetland protection.

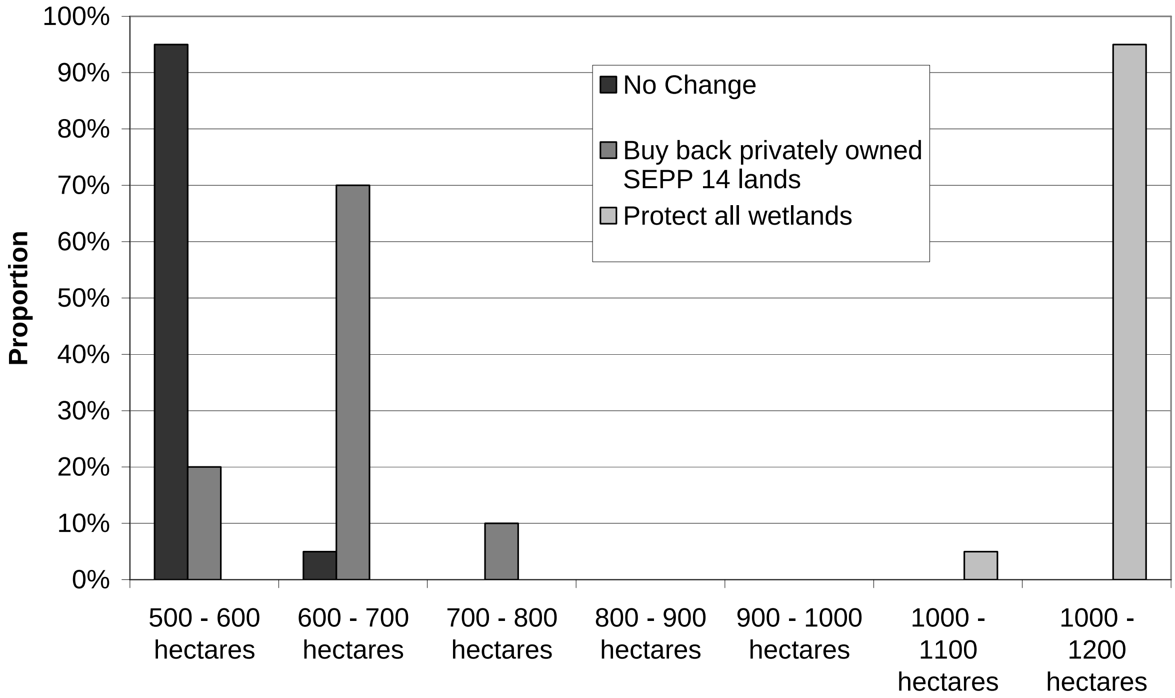

Figure 8. Impacts of SEPP14 wetland protection on the area of protected wetlands

5 Discussion of the Results

This sustainability assessment report has provided a sample of results for management of the ICOLL's entrance, rural drainage options and SEPP14 wetland management. These options are a small subset of the total number of scenarios which can be considered by the Belongil 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.

With increases in the m AHD at which the ICOLL is opened (natural or artificial), there is an increase in lake and flood levels and consequently the inundation of urban property, farmland, sand and mud flats and melaleuca forests. These increases in the inundation of urban property and farmland lead to a very small to small increase in community costs. Entrance management scenarios did not impact water quality inputs to the ICOLL other than ASS inputs, although with flushing TSS concentrations do show changes with the 1.2 m AHD and natural opening regime options. The impacts of permanently opening the ICOLL have mixed with impact on estuary water quality. Changes to the water quality in the estuary and inundation have mixed impacts on aquatic and terrestrial ecological values. However, all scenario options suggest a very small to small increase in the vulnerability of migratory bird populations, reflecting increased inundation of mud and sand flats and melaleuca forest. The entrance management runs illustrate the complexity of the Belongil system, showing that the different entrance management strategies have quite varied and complex impacts on terrestrial and aquatic ecology of the ICOLL and its catchment. They reflect the impacts of entrance management on lake water level and flushing and consequent effects on inundation and estuary water quality. All options lead to negative consequences in some values and positive effects on others. No option is preferable in all impacts. Thus the decision to change the entrance management strategy for Belongil Creek needs to consider fairly complex trade-offs.

Rural drainage options had a range of impacts. Installing WCS at Ewingsdale Rd reduced ASS inputs to the ICOLL, reducing Al, Fe and increasing pH. The Decouple Cumbebin Swamp option was the least effective of all drainage options at reducing ASS inputs to the lake. Decoupling Belongil Swamp generally has ecological benefits with only minor negative impacts for a few nodes. This option has significant benefits in terms of decreasing fish kills. While not as effective as implementing all drainage options (with and without a permanently open entrance), this may be a relatively low cost option for the level of impact it achieves. Implementing all drainage options generally shows a cumulative impact, such that there are moderate to large impacts in lake flushing, ASS inputs, saltmarsh, pH, farmland inundation, Al, Fe, DO, black water inputs, decouple hydrology and fish mobility. The last two options considered were the combinations of all rural drainage options with the extreme entrance management options: no artificial opening and maintaining the entrance opening. The drainage options scenario and entrance management combinations show mixed impacts across all nodes in the Belongil CLAM and illustrate the complexities of the Belongil system and the difficulties of identifying impacts of combined management options. Drainage options and a permanently open entrance have clear benefits in terms of ASS inputs, pH in the ICOLL and fish kills. However, these benefits may be at the expense of other ecological or social values in the ICOLL and its catchment.

The best outcome for wetlands in the Belongil Creek catchment would be the protection of all wetlands followed by buy back of privately owned wetlands. Currently, this node is not linked to other variables (e.g. wetland fauna). Future updates of the Belongil CLAM should consider adding this link and others to demonstrate other possible benefits of wetland protection.

6 ACKNOWLEDGEMENTS

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APPENDIX 1. SUMMARY OF NODES IN THE BELONGIL CLAM TOOL

Node	Description	Output States	Units
Algal Blooms	The concentration of chlorophyll-*a* in the Belongil ICOLL	0 – 5, 5 – 10, 10 – 15, 15 – 20, 20 – 25, 25 – 30, 30 – 35, >35	$\mu g\ L^{-1}$
Area of protected wetlands	Indicates the area of wetlands in the Belongil ICOLL catchment protected under legislation	500 – 600, 600 – 700, 700 – 800, 800 – 900, 900 – 1000, 1000 – 1100, 1100 – 1200	hectares
ASS inputs	Average H_2SO_4 load	30-40, 40-50, 50-60, 60-70, 70-80, 80-90, 90-100	$kg.d^{-1}$
Belongil Al	Indicates the likely percentage change in aluminium (Al) concentrations in the main estuarine reach of the Belongil ICOLL	>10% reduction, <10% reduction, no change, <10% increase, >10% increase	%
Belongil DO	Belongil DO refers to median dissolved oxygen following minor flooding events (<2 year ARI); concentrations within the Belongil ICOLL	0 – 1, 1 – 2, 2 – 3, 3 – 4, 4 – 5, 5 – 6, 6 – 7, 7 – 8	$mg.L^{-1}$
Belongil Fe	Indicates the likely percentage change in iron (Fe) concentrations in the main estuarine reach of the Belongil ICOLL	>10% reduction, <10% reduction, no change, <10% increase, >10% increase	%
Belongil pathogens	Indicates the likely pathogen (faecal coliform) concentrations in the main estuarine reach of the Belongil ICOLL	0-10, 10-100, 100-500, 500-1000, 1000-10000	cfu/100ml (CFU = colony forming units)
Belongil pH	Indicates the likely mean pH of the main estuarine reach in the Belongil ICOLL	5.0-5.2, 5.2-5.4, 5.4-5.6, 5.6-5.8, 5.8-6.0, 6.0-6.2, 6.2-6.4, 6.4-6.6, 6.6-6.8, 6.8-7.0	
Belongil TN	Indicates the likely Total Nitrogen (TN) concentrations in the main estuarine reach of the Belongil ICOLL	<0.2, 0.2 – 0.6, 0.6 – 1.0, 1.0 – 1.4, 1.4 – 1.8, 1.8 – 2.4, >2.4	$mg.L^{-1}$
Belongil TP	Indicates the likely Total Phosphorus (TP) concentrations in the main estuarine reach of the Belongil ICOLL	<0.02, 0.02 – 0.05, 0.05 – 0.1, 0.1 – 0.15, 0.15 – 0.2, 0.2 – 0.25, >0.25	$mg.L^{-1}$
Belongil TSS	Indicates the likely Total Suspended Solids (TSS) concentrations in the main estuarine reach of the Belongil ICOLL	0-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35, >35	$mg.L^{-1}$

Black water inputs	'Blackwater' is a term to describe deoxygenated water emanating from inundated backswamps and low lying agricultural land. Output units are average dissolved oxygen concentration of backswamp drainage assuming inundation to 1.2m AHD	0 – 1, 1 – 2, 2 – 3, 3 – 4, 4 – 5, 5 – 6, 6 – 7, 7 – 8	$mg.L^{-1}$
Community costs	Indicates the expected change in community costs associated with management decisions	>10% decrease, <10% decrease, no change, <10% increase, >10% increase	%
Community health	Indicates the expected change in community health associated with management decisions	>10% decrease, <10% decrease, no change, <10% increase, >10% increase	%
Decouple hydrology	Indicates the relative area (%) of land below 1.2m AHD with hydrology decoupled from estuarine influence by Rural Drainage scenarios	0, 1 – 10, 10 – 20, 30 – 40, 40 – 50	%
Farmland inundation	Indicates the percentage of total rural land likely to be inundated by floods under different management scenarios	5-10% reduction, <5% reduction, no change, <5% increase, 5-10% increase, 10-15% increase, 15-20% increase	%
Fish kills	Indicates the probability of a fish kill occurrence (% chance of occurrence) in the main estuarine reach of the Belongil ICOLL	0, 0 – 25, 25 – 50, 50 – 75, 75 – 100	%
Fish mobility	Indicates broad changes to the potential for fish passage within, to and from the Belongil ICOLL	>10% reduction, <10% reduction, no change, <10% increase, >10% increase	%
Flood levels	Indicates the mean maximum flood level of a minor flood (less than 2 year ARI) throughout the Belongil ICOLL catchment	<0.9, 0.9 – 1.0, 1.0 – 1.2, 1.2 – 1.5, 1.5 – 2.0	m AHD
ICOLL aquatic diversity	Indicates broad changes to the diversity of aquatic organisms in the Belongil ICOLL	>10% reduction, <10% reduction, no change, <10% increase, >10% increase	%
Lake flushing	freshwater replacement time	3.5 - 4.0, 4.0 - 4.5, 4.5 – 5.0, 5.0 - 5.5, 5.5 - 6.0, 6.0 - 6.5, 6.5 - 7.0, >30	days

Lake level	Indicates the mean water level in the ICOLL just upstream of the Ewingsdale bridge (excluding high flow events)	0 – 0.2, 0.2 – 0.4, 0.4 – 0.6, 0.6 – 0.8, 0.8 – 1.0, 1.0 – 1.2, >1.2	m AHD
Local revenue	Indicates the expected change in local revenue associated with management decisions	>10% decrease, <10% decrease, no change, <10% increase, >10% increase	%
Mangroves	Indicates the percentage of total mangrove forest area negatively impacted by changes to hydrology	>10% reduction, <10% reduction, no change, <10% increase, >10% increase	%
Melaleuca forest inundation	Indicates the percentage of total Melaleuca ("Swamp") forest area subject to short-term inundation during minor floods (less than 2 year ARI)	<10% reduction, no change, <10% increase, 10-15% increase, 15-20% increase, >20% increase	%
Migratory bird populations	Vulnerability of migratory bird populations	Decrease, No change, Increase	
Mosquito numbers	Indicates the expected change in mosquito populations associated with management decisions	>10% reduction, <10% reduction, no change, <10% increase, >10% increase	%
Native vegetation area	The area of native vegetation in the Belongil ICOLL subcatchment	1500 – 1600, 1600 – 1700, 1700 – 1800, 1800 – 1900, 1900 – 2000, 2000 – 2100, 2100 - 2200	hectares
Native vegetation connectivity	The percent area of defined wildlife corridors in the Belongil ICOLL subcatchment that are covered with native vegetation rather than cleared and/or weedy vegetation	40 - 50 %, 50 - 60%, 60 - 70%, 70 - 80 %, 80 - 90%, 90 - 100%	%
Pathogen inputs	Quantitative estimation and modeling of pathogen inputs from point sources and difuse sources.	<14, 14-100, 100-300, 300-1000, >1000	CFU/100ml (CFU = colony forming units)
Permanent population	The number of people residing permanently in Byron Bay, Sulffolk Park and Sunrise Beach urban areas	>10% decrease, <10% decrease, no change, <10% increase, >10% increase	%
Recreational fishing	Indicates broad changes in recreational fishing potential in the Belongil ICOLL	>10% reduction, <10% reduction, no change, <10% increase, >10% increase	%
Salinity	Indicates the likely mean salinity (PSU) of the main estuarine reach in the Belongil ICOLL	0-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35, >35	

Saltmarsh	Saltmarsh describes the net loss or gain of saltmarsh communities as a percentage of the existing saltmarsh area	>15% decrease, <15% decrease, no change, <15% increase, >15% increase	%
Sand mud flat inundation	Indicates the percentage of total sand and mudflat area subject to long term inundation (i.e. longer than one tidal cycle)	>10% reduction, <10% reduction, no change, <10% increase, >10% increase	%
Seagrass	Qualitative assessment of seagrass communities. Currently, there is no seagrass growing in the creek system, although there has been in the past. An increase in seagrass suggests that conditions in the estuary will more suited to re-colonisation by seagrass communities	Decrease, No change, Increase	
Swimming	A qualitative assessment of the change in swimming in Belongil Creek	Decrease, No change, Increase	
Terrestrial fauna	Indicates the expected change in terrestrial fauna populations associated with management decisions	>10% decrease, <10% decrease, no change, <10% increase, >10% increase	%
Terrestrial habitat	Indicates the expected change in terrestrial habitat associated with management decisions	>10% decrease, <10% decrease, no change, <10% increase, >10% increase	%
TN inputs	The concentration of Total Nitrogen (TN) entering the ICOLL from point sources and diffuse sources	< 1000, 1000 – 3000, 3000 – 5000, 5000 – 7000, 7000 – 9000, 9000 – 11000, >11000	kg/year
Tourist population	The number of tourists visiting Byron Bay, Sulffolk Park and Sunrise Beach urban areas	>10% decrease, <10% decrease, no change, <10% increase, >10% increase	%
TP inputs	The concentration of Total Phosphorus (TP) entering the ICOLL from point sources and diffuse sources	< 200, 200 – 600, 600 – 1000, 1000 – 1400, 1400 – 1800, > 2000	kg/year
TSS inputs	Describes the concentration of Total Suspended Solids (TSS) entering the ICOLL from diffuse sources	<40000, 40000 – 60000, 60000 – 80000, 80000 – 1000000, 100000 – 120000, 120000 – 140000, >140000	kg/year

Urban flood risk	The increase in urban area at risk of flooding due to potential new development in flood prone areas	<1% increase, 1-10% increase, 10-20% increase, >20% increase	%
Urban property inundation	Indicates the percentage of total urban property likely to be inundated by floods under different management scenarios	>10% reduction, <10% reduction, no change, <10% increase, >10% increase	%
Visual amenity	A qualitative assessment of visual amenity associated with water quality and native vegetation	Decrease, No change, Increase	
Wetland fauna	A qualitative assessment of the vulnerability of 'Wetland Fauna' population	Decrease, No change, Increase	

APPENDIX 2. ADDITIONAL SCENARIO GROUPS AVAILABLE IN THE CLAM TOOL

1. Flood management
2. Climate change
3. Urban development controls
4. Entrance Management
5. Rural drainage
6. Belongil Fields
7. Sunnybrand Chickens
8. Byron Bay density
9. STP management
10. SEPP14 wetland protection
11. Becton
12. Public Education
13. Riparian management
14. Sunrise Beach
15. High conservation value vegetation
16. Urban drainage
17. Septics

Flood management
This scenario is intended to provide insight into the impact on the area of flood prone urban areas in the Belongil ICOLL catchment, associated with a range of possible development controls for potential new developments.

Data for this scenario was extracted from the available documents at the time of completion (SMEC, 2006; BSC, 2006a; BSC, 2006b). The current draft of the flood study is known to contain inaccuracies; data was therefore extracted from the flood study scenario maps by rough estimation of % cover of new developments (rather than accurate measurement). The area of potential new developments was assumed to be the same as those described in the Draft Local Environment Plan (LEP) for the Byron Bay area (2006) and Draft Byron Bay Development Control Plan (DCP) (2006), although the Draft LEP for the Byron Bay area has now been abandoned as a planning instrument.

The scenario options are:

- No change – Development controls would permit dwellings only on land above the 1% Annual Exceedance Probability (AEP)
- Development only on land above the Probable Maximum Flood (PMF) - Potential new developments would only permit dwellings on land above the Probable Maximum Flood (PMF) level.

REFERENCES:
SMEC, 2006, The Preliminary Draft Belongil Creek Flood Study, Byron Shire Council
BSC, 2006a, Draft Local Environment Plan for the Byron Bay area, Byron Shire Council
BSC, 2006b, Draft Byron Shire Council Development Control Plan, Byron Shire Council

Urban development controls
This scenario is intended to provide information on the effects of management options for urban development controls on water quality, human health and flooding in the ICOLL.

The current scenario options are:

- No change
- Mandatory on-site retention of water
- Use of permeable surfaces in new development
- Mandatory mosquito reduction practices

Belongil Fields
This scenario is intended to provide information on the effects of Belongil Fields development on water quality, human health, flooding, native vegetation in the Belongil ICOLL and its catchment.

The Draft Local Environment Plan (LEP) for the Byron Bay area (2006a) and Draft Byron Bay Development Control Plan (DCP) (2006b) have been used as a guide, however, The Draft (LEP) for the Byron Bay area (2006a) has now been abandoned as a planning tool, and the data required to adequately populate this was not all available at the time of construction of the CLAM tool. As such, general estimates of trends based on assumptions rather than data, have been used for this scenario.

The current scenario options are:
- No change
- Low density
- High density

REFERENCES:
BSC, 2006a, Draft Local Environment Plan for the Byron Bay area, Byron Shire Council
BSC, 2006b, Draft Byron Shire Council Development Control Plan, Byron Shire Council

Sunnybrand chickens
This scenario is intended to provide information on the effects of management options for Sunnybrand chickens on water quality in the ICOLL.

No data was provided on the concentrations of pollutants in the effluent or the hydraulic loading to the Belongil Creek from Sunnybrand chickens. As such this scenario does not currently provide an accurate guide.

The current scenario options are:
- No change
- No effluent entering the Belongil waterways

Byron Bay density
This scenario is intended to provide information on the effects of various development densities in existing urban areas of Byron Bay on water quality, human health, flooding, native vegetation in the Belongil ICOLL and its catchment.

The Draft Local Environment Plan (LEP) for the Byron Bay area (2006a) and Draft Byron Bay Development Control Plan (DCP) (2006b) have been used as a guide, however, The Draft (LEP) for the Byron Bay area (2006a) has now been abandoned as a planning tool, and the data required to adequately populate this was not all available at the time of construction of the CLAM tool. As such, general estimates of trends based on assumptions rather than data, have been used for this scenario.

The current scenario options are:
- No change
- Decrease residential to lower density
- Increase residential to medium density
- Increase residential to high density
- Increase CBD commercial development to higher density

REFERENCES:
BSC, 2006a, Draft Local Environment Plan for the Byron Bay area, Byron Shire Council

BSC, 2006b, Draft Byron Shire Council Development Control Plan, Byron Shire Council

STP management
The STP management scenario aims to give insights into how changes in management options impacts on water quality in the ICOLL.

The changes in STP inputs to the ICOLL due to changes in the area of wetland polishing ponds were modelled using the Reed Model for constructed wetland performance modelling by David Pont from Ecotech Group, Lismore (Pont, 2006).

The current scenario options are:
- No change – Current level of reuse, area of wetland polishing ponds = 15ha, current nutrient concentrations, current hydrological loads
- 100% reuse of discharge – no effluent from the STP would be discharged to the Belongil Creek
- Decrease in wetland polishing ponds – The area of the wetland polishing pond reduced to 8ha
- Increase in the area of wetland polishing ponds – the area of wetland polishing ponds increased to 19ha.
- Increase in the area of wetland polishing ponds – the area of wetland polishing ponds increased to 27ha
- Increase in nutrient concentrations discharged to the ICOLL – nutrient concentrations increased by 50%
- Increase in STP hydrological load to the ICOLL – hydrological load increased by 20%

REFERENCES:
Pont, D. (2006) West Byron Constructed Wetland Modelling Report. BSC

Becton
This scenario is intended to provide information on the effects of Becton development on water quality, human health, flooding, native vegetation in the Belongil ICOLL and its catchment.

The Draft Local Environment Plan (LEP) for the Byron Bay area (2006a) and Draft Byron Bay Development Control Plan (DCP) (2006b) have been used as a guide, however, The Draft (LEP) for the Byron Bay area (2006a) has now been abandoned as a planning tool, and the data required to adequately populate this was not all available at the time of construction of the CLAM tool. As such, general estimates of trends based on assumptions rather than data, have been used for this scenario.

The current scenario options are:
- No change (Low-rise family-oriented, low-key tourist development)
- High density
- Very high density
- Reforestation of key habitat areas and corridors

REFERENCES:
BSC, 2006a, Draft Local Environment Plan for the Byron Bay area, Byron Shire Council
BSC, 2006b, Draft Byron Shire Council Development Control Plan, Byron Shire Council

Public education
This scenario is intended to provide information on the effects of management options for Public education on water quality in the ICOLL.

Currently it assumes that implementation of educational programs results in a 15% decrease in nutrients entering the ICOLL. This assumption needs to be updated with more reliable estimates.

The current scenario options are:

- No change
- Implement programs

Riparian management
This scenario is intended to provide information on the effects of management options for riparian management on water quality in the ICOLL.

Currently there is no data available on the extent of riparian connectivity and livestock access to the waterways. As such there is no data currently in this scenario, it has been included to facilitate future model population with riparian buffer data.

The current scenario options are:

- No change
- 50m buffers

Sunrise Beach
This scenario is intended to provide information on the effects of Sunrise Beach development on water quality, human health, flooding, native vegetation in the Belongil ICOLL and its catchment.

The Draft Local Environment Plan (LEP) for the Byron Bay area (2006a) and Draft Byron Bay Development Control Plan (DCP) (2006b) have been used as a guide, however, The Draft (LEP) for the Byron Bay area (2006a) has now been abandoned as a planning tool, and the data required to adequately populate this was not all available at the time of construction of the CLAM tool. As such, general estimates of trends based on assumptions rather than data, have been used for this scenario.

The current scenario options are:

- No change
- Low density
- High density

REFERENCES:
BSC, 2006a, Draft Local Environment Plan for the Byron Bay area, Byron Shire Council
BSC, 2006b, Draft Byron Shire Council Development Control Plan, Byron Shire Council

High conservation value vegetation
This scenario is intended to provide information on the effects of management options for improving the extent, connectivity and ecological status of high conservation value vegetation in the Belongil ICOLL catchment.

The current scenario options are:

- No change
- 50m buffers between developments and HCV
- Reforestation of 'cleared mapped' corridors

The data used was extracted from GIS layers provided by Byron Shire Council (BSC). The data was provided in a report (Burns, 2006.

REFERENCES:

Burns, C. 2006, WetlandCare Australia's Belongil CLAM GIS report. BSC.

Urban drainage

This scenario is intended to provide information on the effects of management options for urban drainage on water quality and flooding in the ICOLL.

The current scenario options are:

- No change
- Increase the size of the town drain
- Enlarge the enlarge culvert under railway line
- Enlarge culvert + redirect Clarkes Beach outlet to Belongil
- Enlarge culvert + redirect Clarkes Beach outlet + install quality and quantity controls
- Improve drainage of the industrial estate

Septics

This scenario aims to indicate the impact on water quality due to septic tanks which may be connected to the Belongil waterways through seepage.

There was no data available at the time of the Belongil CLAM construction on which to base this scenario. It has been included to facilitate future addition of reliable data.

The current scenario options are:

- No change – current number of septics connected to the Belongil Creek and ICOLL
- Implement programs – assumes a 15% reduction in septics connected to the Belongil waterways