



# Dalhousie Creek Sustainability Assessment Report July 2007

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## EXECUTIVE SUMMARY

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

- Water quality and hydrology – there is a need for improved data on creek conditions and event processes including water quality (water colour, turbidity, BOD and DO and nutrients) and hydrology in the catchment.
- Sediment and nutrient exports - event data of sediment exports from forestry areas or nutrient exports from horticulture.
- Dam management – the options for environmental flows needs improvements to knowledge including the volume and outflow arrangements of the two dams, the water quality and likely flow patterns from the catchment.
- Fisheries data – there is a lack of information on catch statistics to underpin the economic, social and environmental values of fisheries.

A range of scenarios in the Dalhousie Creek CLAM are analysed in this report, as recommended in a workshop with the Bellingen Shire Council on 17 May 2007:

- Vegetation management primarily focussing on the revegetation of riparian zones;
- Sea level rise (predicted rises for 2050 and 2100);
- Management of runoff in State forests;
- Management of runoff for agricultural land, primarily focussed on horticultural land-use, and
- the impact of dam scenarios.

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

### Vegetation management

The option of revegetation of all significant riparian zones was compared to the no change option. The results show:

- riparian zone revegetation is likely to increase areas of native terrestrial vegetation, and decrease community complaints and creek sediments,
- small changes are likely in mangrove, saltmarsh and seagrass dynamics as well as terrestrial fauna, total costs and water quality guidelines.

### Sea level rise

The predicted rises in sea level by 2050 and 2100 are compared to the no change option. The results show:

- the impact of sea level rise appears to be significant due to changes in creek entrance dynamics,
- the changes are greater in the 2050 predicted rise than 2100 due to increased berm height in 2050, counteracted by the greater sea level rise in 2100.

### State forest management

The scenario option of managing state forests sediment exports to natural ecosystem rates is compared to the no change option. The results show:

- managing state forest sediment exports to natural rates has a relatively small impact on Dalhousie Creek values,

- the combined small changes in creek water quality combine to result in a large increase in the probability of the creek meeting water quality guidelines.

#### **Agricultural management**

The scenario options of managing agriculture to BMP's or sediment exports to natural ecosystem rates are compared to the no change option. The results show that:

- managing agricultural runoff has a moderately significant impact on Dalhousie Creek with large impacts on creek entrance dynamics and seagrass area and moderate impacts on creek water quality.

#### **Northern and southern dams**

The scenario options of managing the two dams in the catchment are combined to evaluate the impacts of environmental flows. The results show:

- the removal of both dams is highly likely to result in natural creek flows,
- the impacts of managing each of the dams is additive on environmental flows.

The scenario impacts are based on qualitative data and with more information required to properly assess all impacts, further assessment of the hydrology and water quality of the catchment is needed.

## 1 INTRODUCTION

This Sustainability Assessment report is based on results from the Coastal Lake Assessment and Management (CLAM) tool for Dalhousie 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 CLAM approach was developed in a joint effort by the Australian National University and the Department of Natural Resources. Its objective was to fill the need for Sustainability Assessments of coastal lake systems identified in the Healthy Rivers Commission Independent Inquiry into Coastal Lakes. It is considered to be a key tool to assist in management and planning processes such as the Local Environmental Planning review and development of Estuary Management Plans.

Scenarios presented in this report were identified as an important primary focus during workshops held with Council staff and other stakeholders in 17 May 2007. 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 Dalhousie Creek CLAM and key data gaps which are 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 can however be used to inform such a planning process. When this occurs, results in this report must 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 aquaculture activities. Remediation of impacts through better controls on developments and estuary activities, as well as replanting of riparian areas and fringing wetlands, are frequently being considered by State and Local authorities.

The CLAM tool shows 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 coastal zone management plans. It delivers a high level of community participation and an open and transparent modelling tool, which provides full detail of assumptions made and data used in its population.

The CLAM approach is based on the concept of Bayesian networks but provides additional decision support through tailored interfaces and in-model documentation of model

assumptions and design process. More details on the development and use of CLAM models can be found in Brydon *et al.* (2007), Merritt *et al.* (2007) and Ticehurst *et al.* (2006, 2007).

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

- It allows integration of existing data sets and reports;
- It documents in a transparent way data and assumptions available to be used in making a decision;
- It 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;
- It provides 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;
- It plays 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;
- It provides 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 Context for the CLAM and this Sustainability Assessment

The Coastal Lake Assessment and Management (CLAM) approach was developed as part of a NSW Government project focused on the coastal zone, the Comprehensive Coastal Assessment. In response to the Healthy Rivers Commission's Independent Inquiry into Coastal Lakes (HRC, 02002), a Statement of Intent (SOI) was released by the Cabinet Office in February 2003 stating the Government's commitment to the implementation of the *Coastal Lakes Strategy* (reported in Rissik *et al.*, 2003). The Healthy Rivers' Report recommended the development of Sustainability Assessment and Management Plans for coastal lake systems. The CLAM approach was developed as a Sustainability Assessment tool to assist in the development of such plans. This report also classified all coastal lakes in NSW according to the level of protection and management they required. Classifications were as follows:

- Comprehensive protection – all natural ecosystem processes restored and preserved;
- Significant protection – critical natural ecosystem processes restored and preserved;
- Healthy modified condition – key natural and/or highly valued modified ecosystem processes rehabilitated and retained;
- Targeted repair – habitat conditions for selected key species established.

The first stage of the SOI was to fund the development of sustainability assessments and management strategies of eight priority coastal lakes in NSW. These were Cudgen, Myall, Wollumboola, Burrill, Narrawallee, Coila, Merimbula and Back Lakes. The main aim of the project was to ensure that there is "*no further deterioration or that there is an improvement, in the condition of coastal lakes whilst detailed assessments are conducted (if required) and Lake Management Plans developed and implemented.*" (Rissik *et al.*, 2003).

The CLAM method was developed to enable interim management frameworks to be developed rapidly using the best available knowledge to inform short-term decisions while also providing the opportunity for more information to be collected and used to inform future longer-term decisions and plans. The approach also had to be transferable to other coastal lake systems.

The Dalhousie Creek CLAM has been developed as part of a project funded by the Northern Rivers Catchment Management Authority (NRCMA) entitled "Ensuring sustainable development in coastal lake catchments of NSW Northern Rivers". This project was part of the Northern Rivers Catchment Management Authority (NRCMA) Coastal Management program. It addressed the draft Catchment Action Plan (CAP) Management Target C2: "By 2016 maintain and improve the condition of estuaries and coastal lakes through: completion of management plans for all estuaries (65% by 2009), and sustainability assessment and management plans for all coastal lakes (65% by 2009); and implementation of all priority NRM activities within those plans (65% by 2009)".

The project was funded by the Australian Government's Natural Heritage Trust Strategic Reserve 2004-05. As part of this project CLAMs have been developed for the Northern Rivers CMA area as shown in Figure 1.



Figure 1. Location of the Northern Rivers lake systems for which a CLAM tool was developed

This Sustainability Assessment report provides a summary of impacts relating to five key scenarios and their impacts, as recommended at the Dalhousie Creek CLAM workshop with the Bellingen Shire Council on 17 May 2007. These impacts affect the social, economic and environmental sustainability of the lake system.

This report is primarily intended for key decision makers in the Dalhousie Creek system, including Council and CMA staff, members of the Estuary Management Committees and those in relevant State Government Agencies. It is also expected to be useful to those people involved in the development of environmental impact statements associated with future developments such as urban release areas. The report is likely to be of interest to a wider audience, particularly those likely to be affected by changes to the management of the lake system. As a companion to the Dalhousie Creek CLAM, this report is useful in demonstrating the ways in which the CLAM can be used and results from it interpreted for management purposes. As such it is recommended to any user of the Dalhousie Creek CLAM.

It should be noted that the scenarios presented in this report are not exhaustive. Additional scenarios are presented in the Dalhousie Creek CLAM and should also be considered when a Sustainability Assessment and Management Plan is developed.

### **1.3 How should the CLAM tool and results in this Sustainability Assessment Report be used?**

The Dalhousie Creek CLAM tool and the results provided in this Sustainability Assessment report should be used sensibly. As with all models, results from the CLAM must be critically evaluated for their appropriateness before being used to make decisions. All assumptions used in populating the CLAM and any expert review of the data are documented in the input pages found with the CLAM model (refer to the Phase 2 Workshop Manual – Merritt et al. 2007). This information must be very carefully considered when using results to make decisions or recommendations. Users should ask:

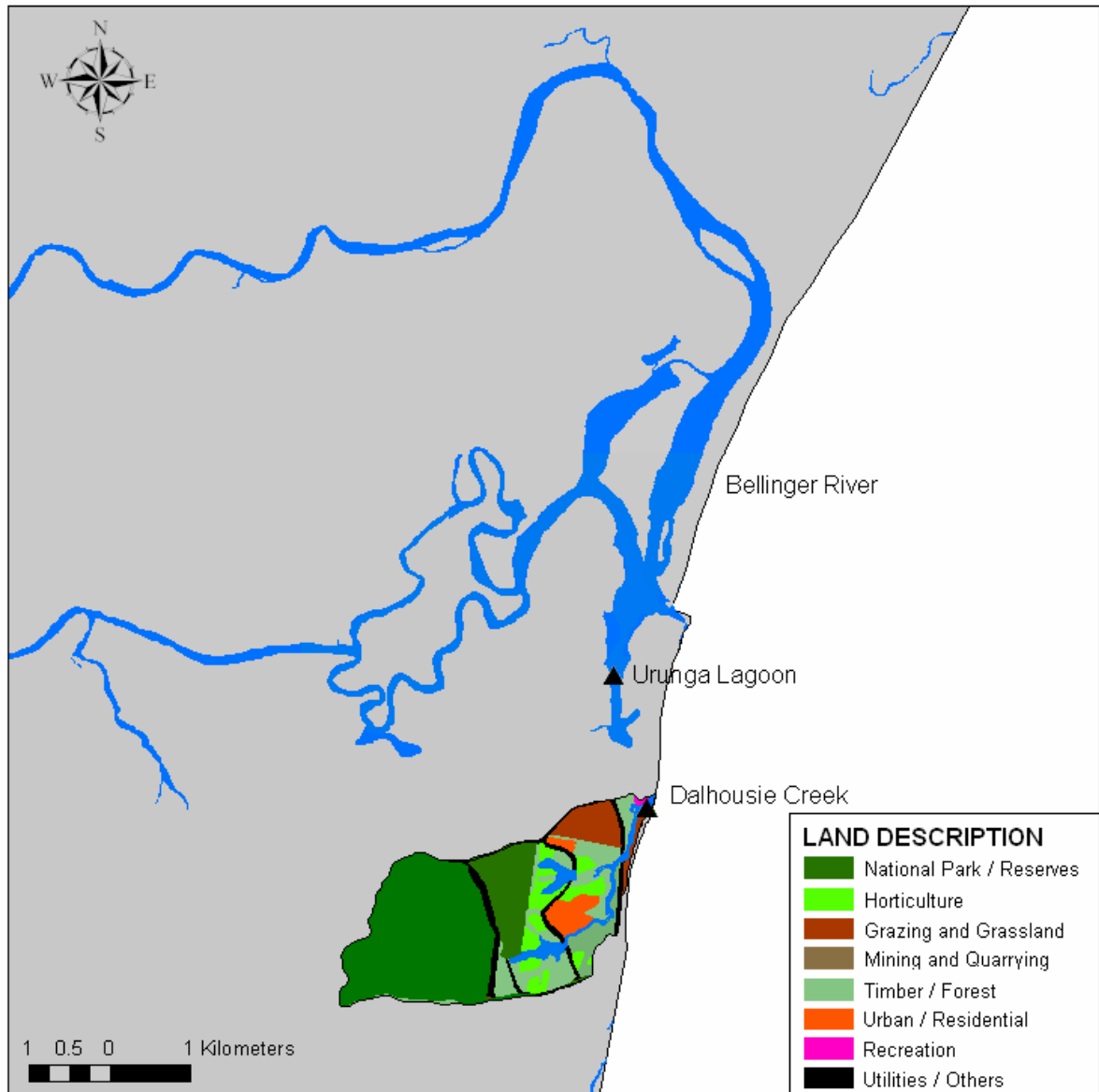
- Does the CLAM consider the specific scenarios you are interested in?
- Do the impacts look reasonable? If not, why not? If yes, why?
- Do you trust the data used to populate the model? Why/why not?
- Is there other better data available that could be used in the model or used to review/validate the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

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

## 2 DALHOUSIE CREEK

### 2.1 Overview

Dalhousie Creek is a saline creek lagoon located approximately 25km south-southwest of Coffs Harbour on the NSW north coast, and situated in the Bellingen Shire Council (BSC) Local Government Area. The creek and its catchment are shown in Figure 2.



**Figure 2. Dalhousie Creek and its catchment**

The creek enters the sea at Hungry Head, a very small village with tourist cabins, and a Surf Club. There are no current plans for substantial development in the catchment (Ian Turnbull, BSC, pers. comm.). The major infrastructure features in the catchment are the Pacific Highway and North Coast Rail Line. Hungry Head and beaches are popular recreational swimming and fishing areas for Urunga/Coffs Harbour and inland areas.

The creek has been reported to have a waterway area of 0.05km<sup>2</sup> and a catchment area of 41 km<sup>2</sup> (NSW Department of Natural Resources (DNR) Estuaries Inventory, February 2007). The

present study however has identified a waterway area of 11.7ha and a catchment area of 636ha from BSC GIS data.

## 2.2 Dams

Two relatively large fresh water dams are situated on two arms of Dalhousie Creek. The smaller southern dam is about 4ha and intercepts flows from about 369ha of mainly forested catchment, but that does include 18.2ha of macadamia plantations. In March 2007 the volume of Southern Dam was estimated to be some 85ML, when the dam level was considered to be about 0.5m below overflow level.

The Northern Dam receives flows from an 83ha catchment that is mainly forested but includes 15.7ha of macadamia plantations. This dam of about 5ha was assessed in March 2007 as having a volume of about 100ML when the dam level was considered to be about 30cm below overflow level. The Northern Dam thus has a longer residence time. Visual inspections have indicated an algal presence that may worsen over time.

## 2.3 Vegetation

BSC has completed vegetation mapping of the area (Flametree Ecological Consulting, 2006) to describe vegetation condition, and identify areas of Endangered Ecological Communities, as well as weed infestations. The majority of the foredune and hind-dune area between Hungry Head and Wenonah Head is classed as having a "High" weed risk rating. No threatened flora was recorded in the Hungry Head to Wenonah Head area. The main threats to the vegetation were seen as fire, and weed infestation.

The utilities (Power line easement, Pacific Highway and Railway line) are seen as sources of vegetation decline and occupy substantial areas of the catchment. The Railway line is affected by weeds, the highway is marked for future upgrade, and the Power line corridor (8ha) contains areas of bare and eroded soils.

## 2.4 The Creek

Council artificially opened the creek at the start of each Christmas holidays until about 1997, but no longer does so, and the creek is now functioning in an uncontrolled manner (Mike Edsall pers. comm.). The creek is reported to naturally breach once or twice per year depending on rainfall and beach conditions.

The NSW DNR Estuaries Inventory (February 2007) describes the creek as having no saltmarsh, seagrass or mangroves, and with a waterway area of 5.1ha. Visual inspections have shown extensive stands of mangroves and saltmarsh. A bed of seagrass has been reported by residents to be present near the Railway Bridge, and one site inspection (21/3/07) observed floating leaves of the small-leaved seagrass *Halophila ovalis* in the upper reaches of the creek lagoon. No algal blooms have been reported.

Commercial and recreational fishing is carried out in the creek. All fishers in the Estuary General Fishery Zone 3 are eligible to harvest in the creek, but only 3 or 4 do so on a regular basis (Geoff Blackburn, Pers. Comm.). At a local scale these fishers operate under an informal management plan approach, and communicate on their periodic operations in the creek. Eels and crabs are the main species taken, with a "very occasional" harvest of bait fish (Geoff Blackburn, Pers. Comm.).

## 2.5 Catchment Land Use

The catchment is composed predominantly of vegetated areas, with logged forest primarily in Newry State Forest, which occupies some 275ha of the catchment west of the Pacific Highway. The highway bisects the catchment in a north-south direction.

The most intensive agriculture is composed of macadamia plantations in the centre of the coastal section of the catchment, occupying about 48 ha (not including the two dams). This area, named Snapper Beach Estate, also contains a rural residential development. Grazing at low intensity occupies 26.18ha. Current land use areas are tabled below:

Land Use	Percentage Area
Water	3.25
Unlogged Bushland/Riparian/Wetlands	12.5
Sand/Beach	1
Unimproved Pasture (Grazing)	3.6
Horticulture	7.5
Urban (Low Density)	4.2
Power line corridor	1.28
Roads	1
Forestry	61.8

All residences in the catchment are serviced by onsite sewage treatment, with no centralised sewage treatment plant (STP). There are 37 registered onsite treatment systems in the catchment, mainly septic tanks and infiltration trenches. Several are Aerated Wastewater Treatment Systems, and there is at least one composting toilet.

Fresh water supplies are also sourced from onsite catchments - with no reticulated water supply. Two pumps and two storages are registered on the Northern Rivers Catchment Management Authority website under Water Sources (NRCMA Website, February 2007).

The DNR Estuaries Inventory states "The way Dalhousie Creek and Lagoon functions is primarily a result of wave energy. It is classed as a strand plain. This means that the estuary would have low sediment trapping efficiency; naturally low turbidity, negative/ salt wedge/ partially mixed circulation and there is low risk of habitat loss due to sedimentation" (DLWC Website, undated). Inspection has shown that creek sediments grade from oceanic sand near the entrance to gravel in the upper reaches.

Although the Dalhousie Creek catchment is relatively undeveloped, the creek is potentially susceptible to eutrophication, particularly from horticulture and onsite sewerage, over time. The relationship of the creek itself to the two dams is complex. It is likely that the dams have protected the creek from pollutant inputs by intercepting flows, but the dams have also retained runoff water that would otherwise enter the creek as environmental flow.

Although little scientific information appears to be available for the creek, the CLAM study provides an opportunity to define baseline values, constraints, areas for future study, and definition of stakeholders' aspirations for a highly valued saline creek. The CLAM project is the first step in a formalised management process that would seek to obtain more accurate and precise information with which to build on the CLAM, and proceed with a sustainable management approach in the meantime.

### 3 DALHOUSIE CREEK CLAM

#### 3.1 Conceptual framework

The Dalhousie Creek CLAM model is underpinned by the conceptual framework shown in Figure 3. This diagram shows the probable dependencies between scenarios (actions) and state variables (values or impacts). This demonstrates, for example, the way in which ecological outcomes such as algal blooms are dependent on water quality parameters such

as total nitrogen. These in turn depend on actions such as state forest management. Definitions for all nodes in this conceptual framework are provided in Appendix 1.

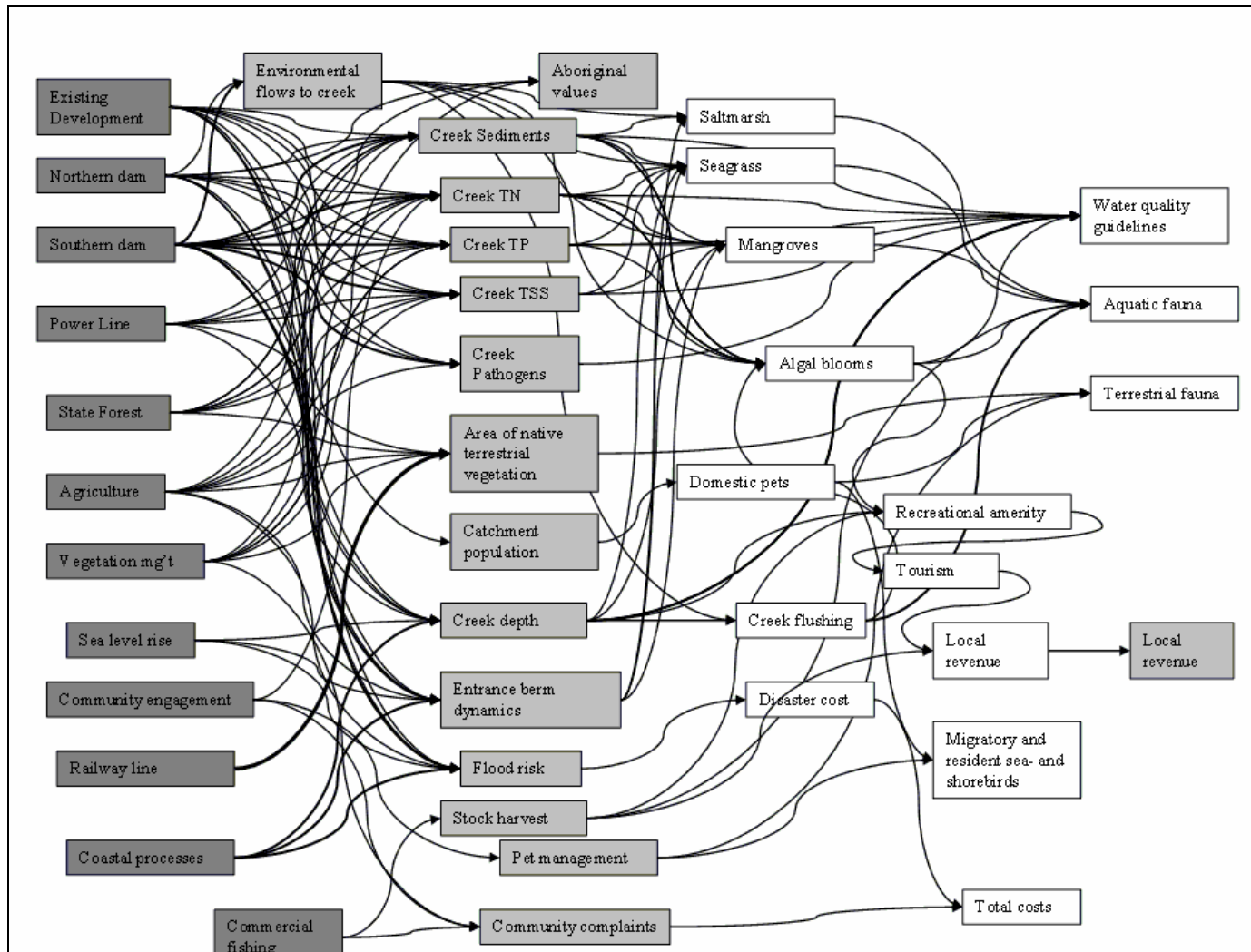


Figure 3. Dalhousie Creek conceptual framework used to underpin the Dalhousie Creek CLAM. Arrows show dependency between nodes. Dark grey boxes represent scenarios which are actions, such as vegetation management, or potential future drivers of the system, such as sea level rise.

### 3.2 Consultation undertaken to develop the Dalhousie Creek CLAM

The framework and scenarios contained in the Dalhousie Creek CLAM were developed in consultation with various stakeholder groups. The majority of consultation was undertaken through the Bellingen Shire Council. In particular Ian Turnbull, Judy Cooney, Peter Plunkett-Cole, Barb and John Piggott, Mohammed Hanif (DNR), Colin Matthews, Wayne Cooper, and Rob Kirwood (Forests NSW) were involved in discussions of feasible scenarios, issues and concerns which were used to develop the conceptual framework.

A second major source of feedback was the Project Reference Group which consists of representatives of the Northern Rivers Catchment Management Authority (CMA), the Department of Natural Resources, the Department of Planning, the Department of Primary Industries and NSW Marine Parks Authority.

Feedback was also received on the issues, framework and scenarios from a representative of the Macadamia growers.

The CLAM user training workshops held in May 2007 provided an opportunity for feedback on the Dalhousie Creek CLAM. Attendees at this workshop included Council staff and a councillor, CMA representatives, staff from State Government Agencies and community members.

### 3.3 An assessment of data quality

The CLAM model relies on a set of conditional probabilities to define the relationship between variables. An example of a conditional probability is as follows: there is a 30% chance of rain tomorrow if it has rained today. That is, a conditional probability is the probability of event B (rain tomorrow) given that event A (rain today) has occurred.

Thus for every arrow in Figure 3, a set of conditional probabilities must be defined which estimates the nature of the relationship between the two variables. The data used to derive these conditional probabilities comes from a variety of sources. These include 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 an assessment of data quality for each node (ie. each box in Figure 3). A statement of priority data collection needs for Dalhousie Creek is then given. This statement was provided by David Pont who put together the data for the Dalhousie Creek CLAM.

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

**Table 1. Subjective assessment of the quality of data used in the Dalhousie CLAM**

Node	Quality of Data	Reason	Suggested improvements
Aboriginal values	Average	Based on assumptions, local consultation and iCAM combination model	Local review
Algal blooms	Average	Based on assumptions and iCAM combination model with some local qualitative data	Expert review and increased knowledge of the interactions between nutrients and algae or phytoplankton response in Dalhousie or similar systems.

Aquatic fauna	Poor	Based on assumptions and iCAM combination model with no local data.	Expert review and increased knowledge of the aquatic fauna found in Dalhousie Creek.
Area of native vegetation	Very good	Based on GIS analysis using large scale landuse data and maps.	Improved through ground-truthing and better definition of native vegetation
Catchment population	Average	Based on assumptions and local population data.	Improved through survey or review of local population dynamics and potential for increased density of current urban areas.
Community complaints	Average	Based on local data, assumptions and iCAM combination model.	Improved through local survey and review.
Creek depth	Average	Based on assumptions, local data, literature review and iCAM combination model.	Expert and local review and local monitoring of runoff and hydrodynamics in Dalhousie Creek.
Creek entrance berm dynamics	Average	Based on assumptions and iCAM combination model using some local input data	Improved through local hydrodynamic study.
Creek flushing	Average	Based on assumptions and iCAM combination model with qualitative local data	Improved through local review and data on dam volumes and creek flows.
Creek pathogens	Average	Based on model with some local data but primarily uncalibrated	Expert review and more comprehensive local data collection and the use of local data for calibration.
Creek sediments	Poor	Based on literature reviewed assumptions and iCAM combination model	Expert and local review and sediment accumulation monitoring program.
Creek TN	Average	Based on a catchment water quality model developed at iCAM using GIS map layers.	Expert and local review and local water quality data.
Creek TP	Average	Based on a catchment water quality model developed at iCAM using GIS map layers.	Expert and local review and local water quality data.
Creek TSS	Average	Based on a catchment water quality model developed at iCAM using GIS map layers.	Expert and local review and local water quality data.
Disaster costs	Poor	Qualitative assessment of impacts from flood risk based on general assumptions.	Modelling of extent of potential flooding and associated costs and incorporation of other disaster costs.

Domestic pets	Average	Based on literature reviewed assumptions (Australia) applied to the local catchment.	Local survey of numbers of pets owned and visiting the catchment.
Environmental flows	Average	Based on literature review and local estimates of dam volumes.	Review and calibrate using targeted local monitoring data.
Flood risk	Average	Based on assumptions and iCAM combination model	Expert and local review and focused hydrodynamic study.
Local revenue	Poor	Based on assumptions related to local area.	Expert and local review and model calibration against local monitoring data.
Mangroves	Average	Based on assumptions, local ground-truthing and iCAM combination model	Expert and local review and model calibration against local monitoring data.
Seabirds and shorebirds	Good	Based on literature reviewed assumptions and iCAM combination model	Assumptions generally well accepted, however local studies would increase certainty in model
Pet management	Average	Based on generally accepted assumptions	Review by local stakeholders and survey of current pet management and attitudes
Recreational amenity	Poor	Based on assumptions and iCAM combination model	Expert and local review and survey of local residents and visitors on what they value for recreational amenity
Saltmarsh	Average	Based on assumptions, local ground-truthing and iCAM combination model	Expert and local review and model calibration against local monitoring data.
Seagrass	Average	Based on assumptions, local ground-truthing and iCAM combination model	Expert and local review and model calibration against local monitoring data.
Stock harvest	Poor	Based on assumptions and iCAM combination model	Local review incorporating information on volume of stock harvested from Dalhousie Creek.
Terrestrial fauna	Average	Based on generally accepted assumptions and a simple summation of impacts.	General direction of impact is considered reliable; however detailed understanding of terrestrial species existing in the catchment and the impact of habitat and domestic pets is required to improve the analysis.
Total costs	Poor	Based on general assumptions and qualitative estimates	Local review
Tourism	Poor	Based on assumptions.	Local review

Water quality guidelines	Average	Based on assumptions and iCAM combination model	Expert and local review and better understanding of the interactions between water quality parameters such as TN, TP and TSS.
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**Excellent:** Models based on local data, supported assumptions, expert review and calibrated/verified with measured (local) data. For direct changes in measured areas where derived from ground-truthed GIS interpretation. Simple yes/no output models.

**Very good:** Models based on local data, supported assumptions, expert review and calibrated/verified with measured (local) data which may be limited in extent

**Good:** Models supported by expert review or local data. May be calibrated/verified with measured (local) data which may be limited in extent or show some areas for improvement of model fit.

**Average:** Uncalibrated models or based on assumptions with some supporting local data or expert review.

**Poor:** Based on untested assumptions with little or no supporting local data or expert review.

Priority data collection areas identified by David Pont are:

- Water quality and hydrology – there is a need for improved data on creek conditions and event processes including water quality (water colour, turbidity, BOD and DO and nutrients) and hydrology in the catchment.
- Sediment and nutrient exports - event data of sediment exports from forestry areas or nutrient exports from horticulture.
- Dam management – the options for environmental flows needs improvements to knowledge including the volume and outflow arrangements of the two dams, the water quality and likely flow patterns from the catchment.
- Fisheries data – there is a lack of information on catch statistics to underpin the economic, social and environmental values of fisheries.
- Horticulture management - a horticulture management study and plan would be a valuable tool in ensuring sustainable operation of the orchards with minimal impacts on the creek.

## 4 SCENARIOS

In order to develop this Sustainability Assessment analysis a relatively small subgroup of scenario combinations were selected from the 82944 available in the Dalhousie Creek CLAM. It was decided to focus on the following scenarios:

- Vegetation management
- Sea level rise
- Forest management
- Agricultural management

These sets of scenarios are considered in isolation to each other. The impacts focused on are the likely consequence of the scenario options (i.e., the highest probability outcome) with particular reference to the following values:

- Water quality (TN, TSS)
- Saltmarsh and seagrass
- Environmental flows and
- Pathogens

The descriptions below for these scenarios are taken from the Dalhousie Creek CLAM tool. Other scenarios available in the CLAM tool are described in Appendix 2.

## 4.1 Vegetation management

Most of the main stream lines through the horticultural, grazing and residential areas of the catchment feature narrow buffers to the stream lines. Riparian zone scenario includes revegetation of all significant riparian zones in the catchment, particularly in the agricultural areas.

The scenario options for vegetation management in Dalhousie Creek CLAM are:

1. No change
2. Riparian zone along streams and waterbodies

## 4.2 Sea Level Rise

Sea level is predicted to rise in line with climate change. Over most of Australia, annual average temperatures will be 0.4 to 2°C greater than 1990 by the year 2030. By 2070, average temperatures are likely to increase by 1 to 6°C (Whetton and Holper, 2001).

Wetter conditions are possible in northern and eastern Australia in summer and inland Australia in autumn. In areas that experience little change or an increase in average rainfall, more frequent or heavier downpours are likely.

Sea level is likely to rise at a rate of between 0.8 and 8.0 cm per decade, reaching 9 to 88 cm above the 1990 level by the year 2100 (Whetton and Holper, 2001; Gabriel and Willcocks, 2004).

These climate change quantitative estimates and scenarios have been updated using the latest Inter-governmental Panel on Climate Change Report (IPCC, 2001 – *Global average sea level rise 1990 to 2100 for the SRES scenarios*):

Year	Minimum rise (m)	Central rise (m)	Maximum rise (m)
2050	0.05	0.17	0.32
2100	0.09	0.4	0.87

The scenario options for sea level rise in the Dalhousie Creek CLAM are:

1. No Change
2. Prediction for year 2050
3. Prediction for year 2100

## 4.3 State Forest Management

State Forest sediment management: Gravel roads are found throughout the forest area managed by Forests NSW, and may export sediments in rainfall events; the dams are likely to intercept most of this sediment; Forests NSW advise that operations are conducted in accordance with the Ecologically Sustainable Management of State Forests Plan (NSW DPI, 2005). However, if flows through the dams are increased, particularly in wet weather, any elevated suspended sediments from the State Forest area may impact directly on Dalhousie Creek.

The scenario options for state forest management in the Dalhousie Creek CLAM are:

1. No change
2. Sediment exports at natural ecosystem rates

## 4.4 Agricultural Management

This scenario examines best-practice and complete solution options for managing the dominant agricultural land use of horticulture in the Dalhousie Creek catchment (total

48.7ha), as well as the smaller area of grazing (23.2ha). The grazing property is only partly cleared, and appears not to be heavily stocked. However, the existing use right suggests the property should be regarded as having the potential for full stocking. The main option for nutrient and sediment export control is the restoration of riparian zones. This is covered by the vegetation management scenario (Section 4.1).

Most of the horticulture is composed of macadamia orchards, and management follows the common pattern on the North Coast of row plantings: mostly bare ground beneath the tree rows for ease of nut harvest, and rows are often planted close to steam lines. Options include a fertiliser and sediment management plan for horticultural areas, and the achievement of nutrient and sediment export controls for all agricultural zones such that these exports are at natural bushland levels.

The scenario options for agricultural land management in the Dalhousie Creek CLAM are:

1. No change
2. Best Practice fertiliser management
3. Sediment and chemical exports reduced to natural rates

#### 4.5 Northern and southern dams

One of the values of particular interest for Dalhousie Creek CLAM stakeholders is environmental flows, defined as the flows of water from the two dams to the creek to maintain and enhance sustainable ecological function. In the model, the northern and southern dam scenarios are the only scenarios that impact on environmental flows. The two Dalhousie dams are constructed on the two main tributaries of the creek and because of their volume intercept a substantial proportion of flows that would otherwise flow to the creek downstream. The question is: what would be the impacts on environmental flow in Dalhousie Creek from different management of the dams, or their complete removal? Environmental flows are provided by either releasing water from storages or by imposing rules which both limit the volume and timing of water extractions by users. In both cases, the objective is to achieve stream flows that mimic the natural flows.

The key assumptions used in the model are:

- The Northern Dam area was assessed from aerial photographs and topographic map as 5ha; field measurement showed a range of depths from which a total volume of about 100.6ML was estimated. The dam was also estimated to be about 30cm below overflow depth (at March 2007). A further factor is the estimated 14,000m<sup>2</sup> of relatively shallow water (<1m) in the dam where withdrawals of water would favour the growth of aquatic plants and increase dam water quality through wetland processes (DLWC, 1998; Lawrence and Breen, 1998). This water, if made available for environmental flows to the creek could amount to about 0.8m depth x 50,000m<sup>2</sup> area = ~40ML if the dam were full at the beginning of the dry season. A reasonable potential flow of 300m<sup>3</sup> per day would provide some 130 days of flow. Complete removal of the dam will decrease the retention function of the dam in the catchment; the Northern dam is larger and drains a smaller catchment.
- The Southern Dam area was assessed from aerial photographs and topographic map as 4ha; field measurement showed a range of depths from which a total volume of about 85.7ML was estimated. The dam was also estimated to be about 50cm below overflow depth (at March 2007). A further factor is the estimated 10,000m<sup>2</sup> of relatively shallow water (<1m) in the dam where withdrawals of water would favour the growth of aquatic plants and increase dam water quality through wetland processes (DLWC, 1998; Lawrence and Breen, 1998). This water, if made available for environmental flows to the creek could amount to about 1.0m depth x 40,000m<sup>2</sup> area = ~40ML if the dam were full at the beginning of the dry season. A reasonable potential flow of 300m<sup>3</sup> per day would provide some 130 days of flow. The Southern dam is smaller, and drains a much larger catchment of some 360ha, and would

experience larger fills and more overflows. Complete removal of the dam will decrease the retention function of the dam in the catchment.

- Some visual evidence of water quality deterioration in the dams exists in the form of visible algae and some bottom sediment accumulation. A major issue is the potential for algae, pathogens and nutrients to overflow with the dam waters to the creek downstream. One impact of allocating increased overflows from the dams will be the tendency for existing wetland plant populations in the areas shallower than 0.6m depth to increase in extent when the water depth is lower. Preliminary assessment indicates about 1ha in the Southern Dam and 1.4ha in the Northern Dam with depth 1m or less that would, be suitable for conversion to wetland with beneficial impacts on water quality (DLWC, 1998; Lawrence and Breen, 1998).
- Currently the impact of extraction has not been considered when calculating the potential change in environmental flows. Estimating that extraction could account for up to 32ML, it could impact upon the probability distributions given below if extraction was only taken from the Southern Dam. It is assumed that extraction is shared between the dams and therefore should not significantly impact upon the information given below.

The scenario options for each dam (northern and southern) in the Dalhousie Creek CLAM are:

1. No Change
2. Increased overflows by dam level changes
3. Water quality control plan
4. Dam removal

## 5 RESULTS FROM SCENARIO RUNS

### 5.1 Vegetation management

Vegetation management options were run in isolation to other scenarios and their impacts considered for all nodes. Table 2 summarises the impacts of vegetation management on all nodes for which there was an impact. This impact is a qualitative assessment of the relative magnitude and direction of change in the variable compared to the 'do nothing' option. Thus a 'small increase' means that the variable is likely to have a value that is a bit bigger than it would have been under the 'do nothing' option.

**Table 2. Impacts of vegetation management on likely state values for impacted nodes.**

Values	20m Riparian zone
Algal blooms	very small decrease
Aquatic fauna	very small increase
Area of native terrestrial vegetation	large increase
Community complaints	large decrease
Creek Pathogens	negligible
Creek sediments	large decrease
Local Revenue	negligible
Mangroves	small decrease
Recreational amenity	very small increase
Saltmarsh	small decrease
Seagrass	small increase
Terrestrial fauna	small increase
Total costs	small decrease
Tourism	very small increase
Water quality guidelines	small increase

Unimpacted nodes were: Aboriginal values; Catchment population; Creek depth; Creek entrance berm dynamics; Creek flushing; Creek TN; Creek TP; Creek TSS; Disaster cost;

Domestic pets; Environmental flows; Flood risk; Migratory and resident seabirds and shorebirds; Pet management; Stock harvest.

The table shows:

- the impact of vegetation management on Dalhousie Creek as a whole appears to be significant with moderate to large changes in area of native terrestrial vegetation, community complaints and creek sediments.
- small changes are also seen in mangroves, saltmarsh and seagrass, as well as terrestrial fauna, total costs and water quality guidelines.
- The localised impacts could be greater.

Figures 4 and 5 show the relatively large impact of vegetation management on creek sediments and terrestrial vegetation. Interestingly, the results indicate no impact on other water quality parameters such as TSS, TP and TN which would suggest that most of the material trapped by vegetation management is likely to be coarser particles that settle rapidly. Alternatively these results may be a result of different modelling approaches as the creek sediments is informed by judgement, whereas the water quality parameters are informed through a developed WQ model.

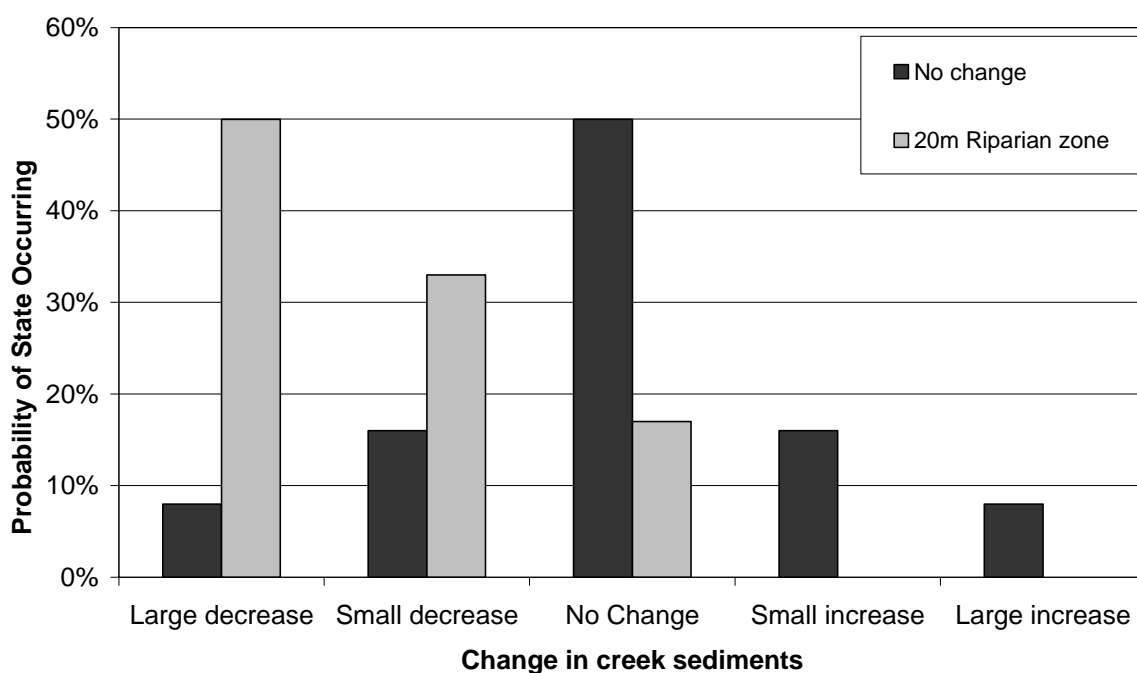


Figure 4. Probability of change in creek sediments under vegetation management scenarios

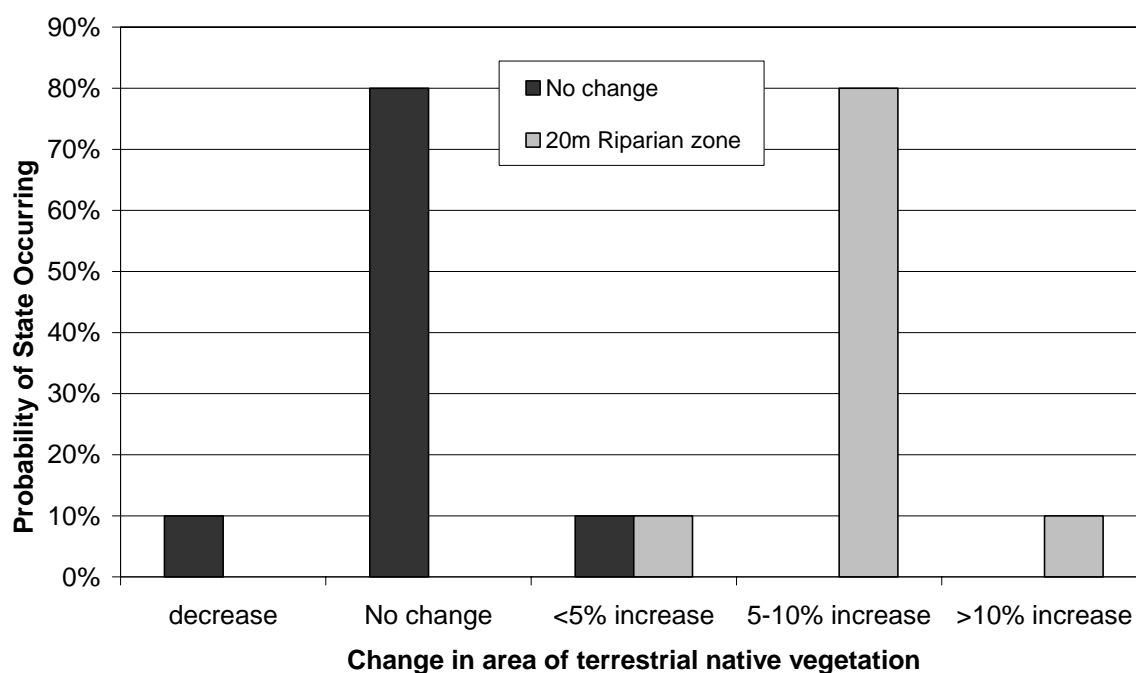


Figure 5. Probability of changes to the area of native terrestrial vegetation under vegetation management scenarios

## 5.2 Sea level rise

Sea level rise options were run in isolation and their impacts considered for all nodes. Table 3 summarises the impacts of Sea level rise on all nodes for which there was an impact.

Table 3. Summary of impacts of sea level rise on likely state values for impacted nodes.

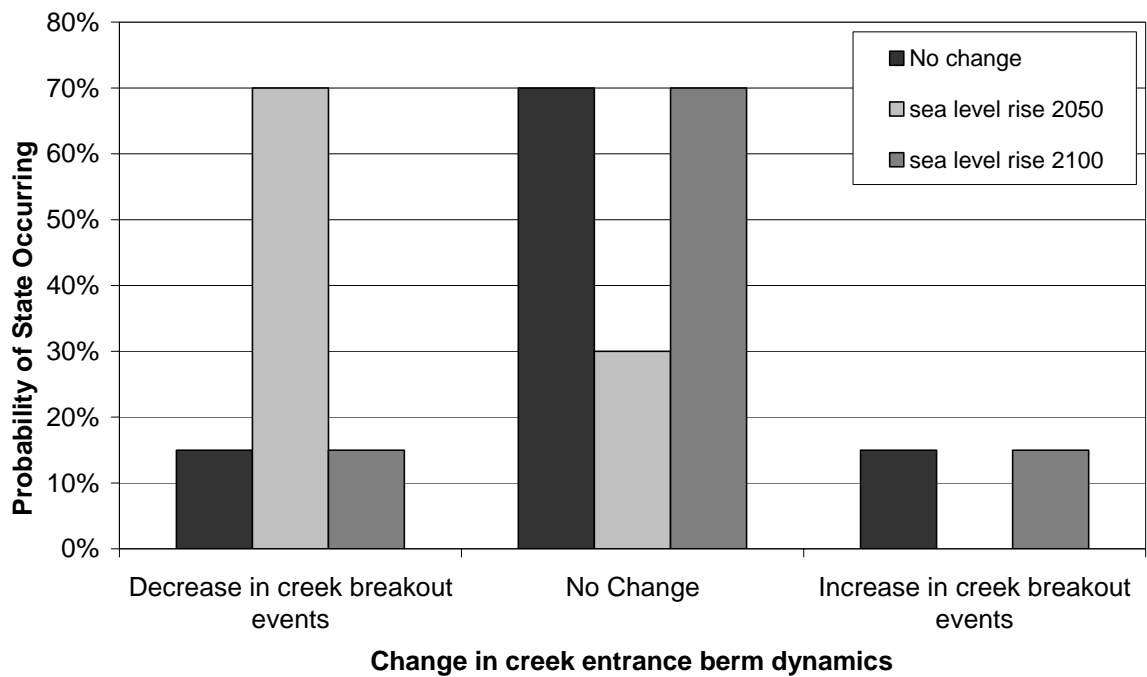
Values	Sea level rise 2050	Sea level rise 2100
Aquatic fauna	large increase	no impact
Creek entrance berm dynamics (breakouts)	large decrease	no impact
Disaster cost	moderate increase	moderate increase
Flood risk	moderate increase	moderate increase
Mangroves	moderate increase	no impact
Saltmarsh	large increase	no impact
Seagrass	large increase	no impact
Total costs	very small increase	very small increase

Unimpacted nodes were: Catchment population; Creek depth; Creek flushing; Domestic pets; Environmental flows; Pet management; Stock harvest; Aboriginal values; Algal blooms; Area of native terrestrial vegetation; Community complaints; Creek Pathogens; Creek TN; Creek TP; Creek TSS; Local Revenue; Migratory and resident seabirds and shorebirds; Recreational amenity; Terrestrial fauna; Tourism; Water quality guidelines; Creek sediments.

The table shows:

- the impact of sea level rise on Dalhousie Creek as a whole appears to be significant, largely due to the predicted changes in creek entrance dynamics.
- The changes are greater in the shorter term (2050 predicted sea level rise) than for the longer term (2100) due to the unique characteristics of Dalhousie Creek entrance.

In the short term, sea level rise is likely to increase creek berm height due to the position of the entrance at the north end of the beach resulting in a decrease in creek breakout events (fig. 6). As sea levels rise further, more effective openings are predicted to return the frequency of breakout events to current (no change) level.



**Figure 6. Probability of changes to the creek entrance berm dynamics from sea level rise scenario**

Figure 7 shows the probability of change in the area of saltmarsh which is likely to increase in the short term before returning to current levels as a result of sea level rise impacts on the creek entrance. A similar impact is seen on the areas of seagrass.

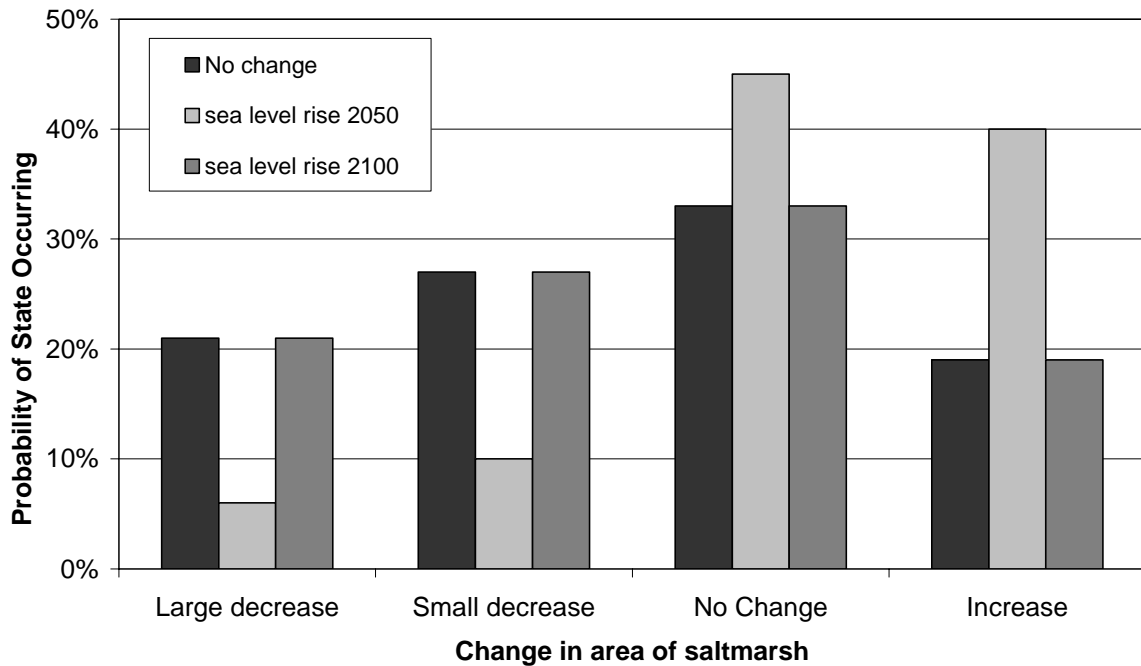


Figure 7. Probability of changes to the area of saltmarsh in Dalhousie Creek from sea level rise scenario.

### 5.3 State Forest management

State Forest management options were run in isolation and their impacts considered for all nodes. Table 4 summarises the impacts of state forest management on all nodes for which there was an impact.

Table 4. Summary of impacts of state forest management on likely state values for impacted nodes

Values	Forest managed to natural export rates
Algal blooms	moderate decrease
Aquatic fauna	small increase
Creek sediments	moderate decrease
Creek TN	small decrease
Creek TP	small decrease
Creek TSS	negligible
Local Revenue	negligible
Mangroves	very small increase
Recreational amenity	small increase
Saltmarsh	small decrease
Seagrass	moderate decrease
Tourism	very small increase
Water quality guidelines	large increase

Unimpacted nodes were: Aboriginal values; Catchment population; Creek depth; Creek ; lushing; Domestic pets; Environmental flows; Pet management; Stock harvest; Area of native; Terrestrial vegetation; Community complaints; Creek entrance berm dynamics (breakouts); Creek Pathogens; Disaster cost; Flood risk; Migratory and resident seabirds and shorebirds; Terrestrial fauna; Total costs.

The table shows:

- the impact of state forest management on Dalhousie Creek as a whole appears to be moderately small
- the combined small impacts on creek water quality result in a large increase in the probability of the creek meeting water quality guidelines.

Figure 8 shows the small to large increase in compliance with water quality guidelines as a result of managing state forest export rates.

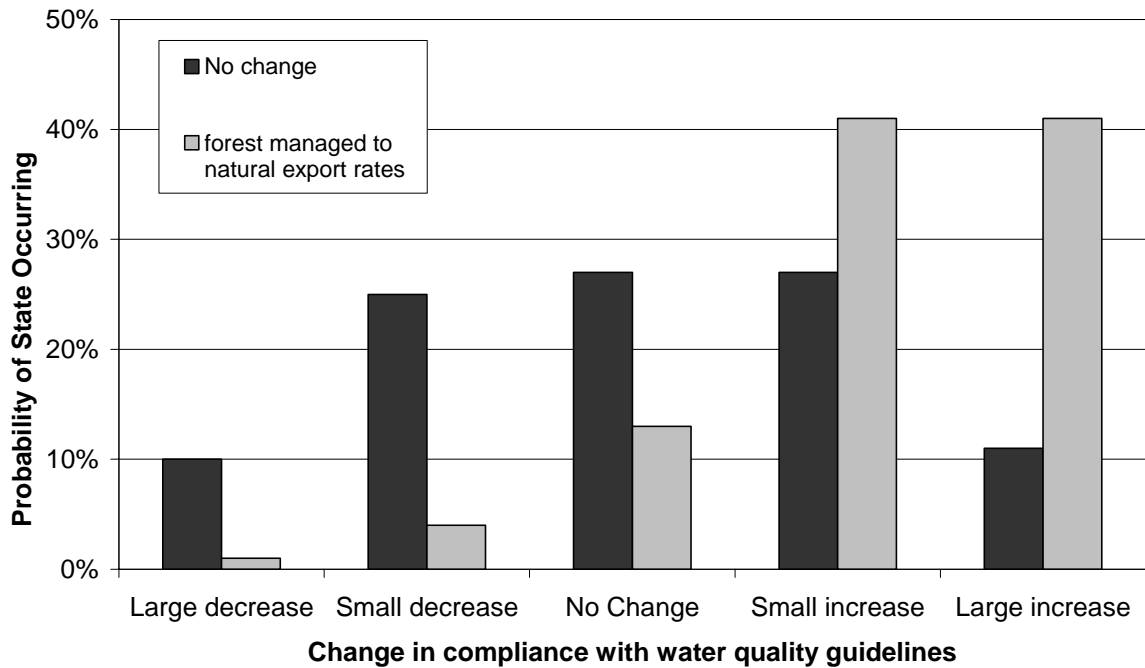


Figure 8. Probability of changes to the water quality guidelines from state forest management options

#### 5.4 Agricultural management

Agricultural management options were run in isolation and their impacts considered for all nodes. Table 5 summarises the impacts of agricultural management on all nodes for which there was an impact.

**Table 5. Summary of impacts of agricultural management on likely state values for impacted nodes.**

Values	Agriculture managed to	
	BMP	Natural export rates
Aboriginal values	small increase	small increase
Algal blooms	very small decrease	small decrease
Aquatic fauna	small increase	moderate increase
Creek entrance berm dynamics (breakouts)	large decrease	large decrease
Creek sediments	moderate decrease	moderate decrease
Creek TN	no impact	moderate decrease
Creek TP	no impact	moderate decrease
Local Revenue	negligible	negligible
Mangroves	very small increase	small increase
Recreational amenity	very small increase	very small increase
Saltmarsh	moderate increase	moderate increase
Seagrass	large increase	large increase
Tourism	very small increase	very small increase
Water quality guidelines	small increase	moderate increase

Unimpacted nodes were: Creek Pathogens; Creek TSS; Disaster cost; Flood risk; Migratory and resident seabirds and shorebirds; Terrestrial fauna; Total costs; Catchment population; Creek depth; Creek flushing; Domestic pets; Environmental flows; Pet management; Stock harvest; Area of native terrestrial vegetation; Community complaints.

The table shows:

- the impact of agricultural management on Dalhousie Creek as a whole appears to be moderately significant, with large impacts on creek entrance dynamics in turn impacting on seagrass area.
- the combined moderate impacts on creek water quality result in a moderate increase in the probability of the creek meeting water quality guidelines.

Figure 9 shows the impact of agricultural management on creek entrance berm dynamics. It is likely that a decrease in peak flows as a result of runoff management will decrease peak discharges rates to the creek, reducing the frequency of creek breakout events.

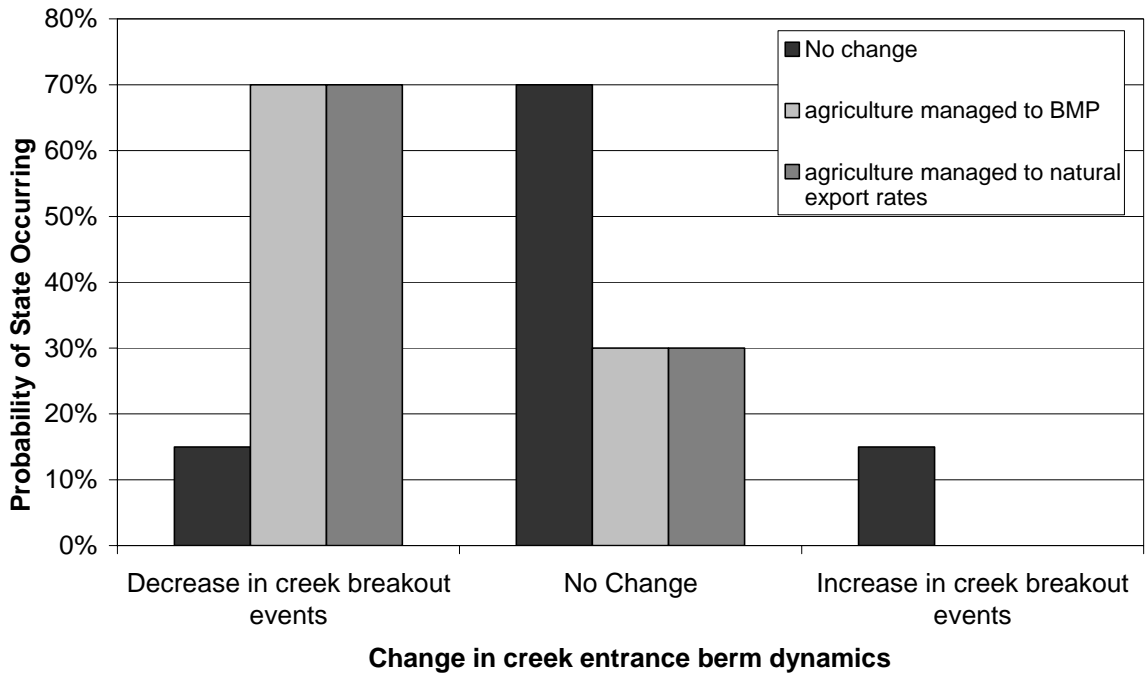


Figure 9. Probability of changes to the creek entrance berm dynamics from agricultural management options

Figure 10 highlights the predicted changes to the area of seagrass as a result of agricultural management. A shift to BMP's or management to natural export rates is likely to result in a small to large increase in the area of seagrass. This is due to a combination of values impacted by the scenario options including creek sediments, creek entrance dynamics, creek TN and TP.

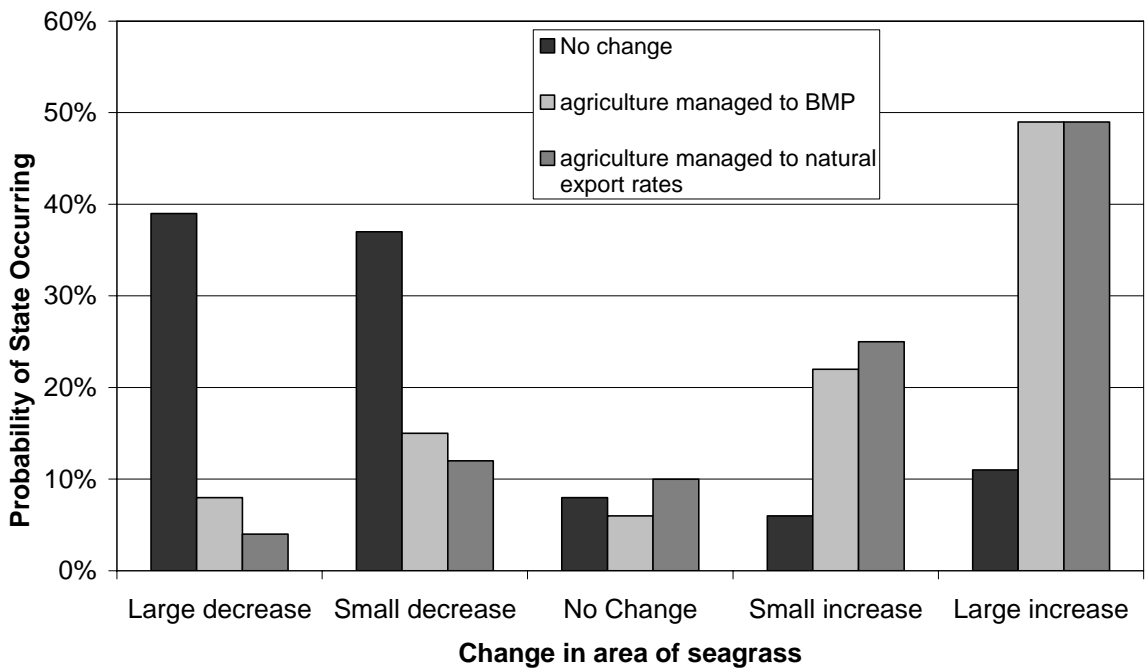
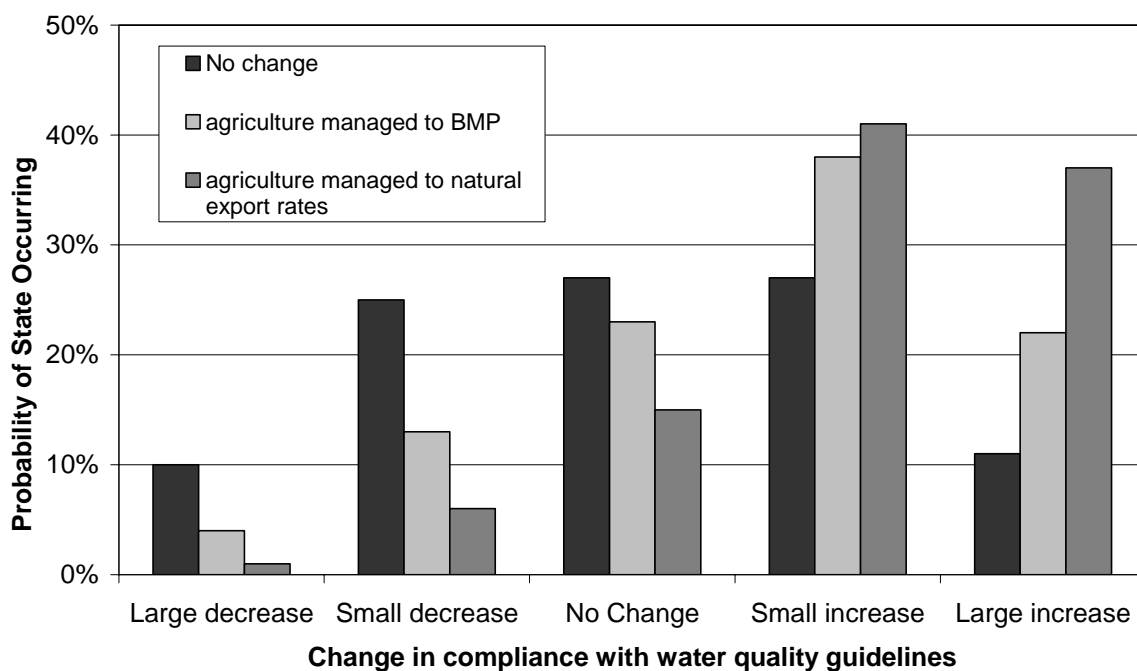


Figure 10. Probability of changes to the area of seagrass from agricultural management options

The combined impacts of agricultural management on creek TN, creek TP and creek sediments results in a small to moderate increase in compliance with water quality guidelines (Figure 11).



**Figure 11. Probability of changes to compliance with water quality guidelines from agricultural management options**

## 5.5 Northern and southern dams

Dam management options were run in combination and their impacts considered for environmental flows. The northern dam was run for each scenario options with no changes in isolation to the southern dam management. Table 6 summarises the impacts of these scenarios on all nodes for which there was an impact.

Unimpacted nodes were: area of native terrestrial vegetation; terrestrial fauna; creek pathogens; catchment population; stock harvest; community complaints; migratory and resident seabirds and shorebirds; domestic pets; pet management.

The table shows:

- the removal of both dams is highly likely to result in natural creek flows,
- the impacts of managing each of the dams is additive on environmental flows.
- large changes are likely to occur in creek sediments with a large increase as a result of the dam overflow scenarios, while large decreases are likely as a result of implementation of water quality plans or removal of dams.
- Moderate to large increases in aboriginal values and in creek breakout events due to entrance berm dynamic changes are likely under all scenarios.

The scenario impacts are based on qualitative data and with more information required to properly assess all impacts, further assessment of the hydrology and water quality of the catchment is needed.

Figure 12 shows the results of the scenario runs on environmental flows, the primary aim of the scenario. Managing overflows in the northern dam is likely to increase environmental flows to

<40 ML. Managing both dams to overflows increases the environmental flows to >40 ML. Removal of one dam results in an increase in the probability of natural flows to 50%, while removing both dams is highly likely to result in natural flows. The model in its current form does not account for changes in flow due to runoff management or other catchment processes.

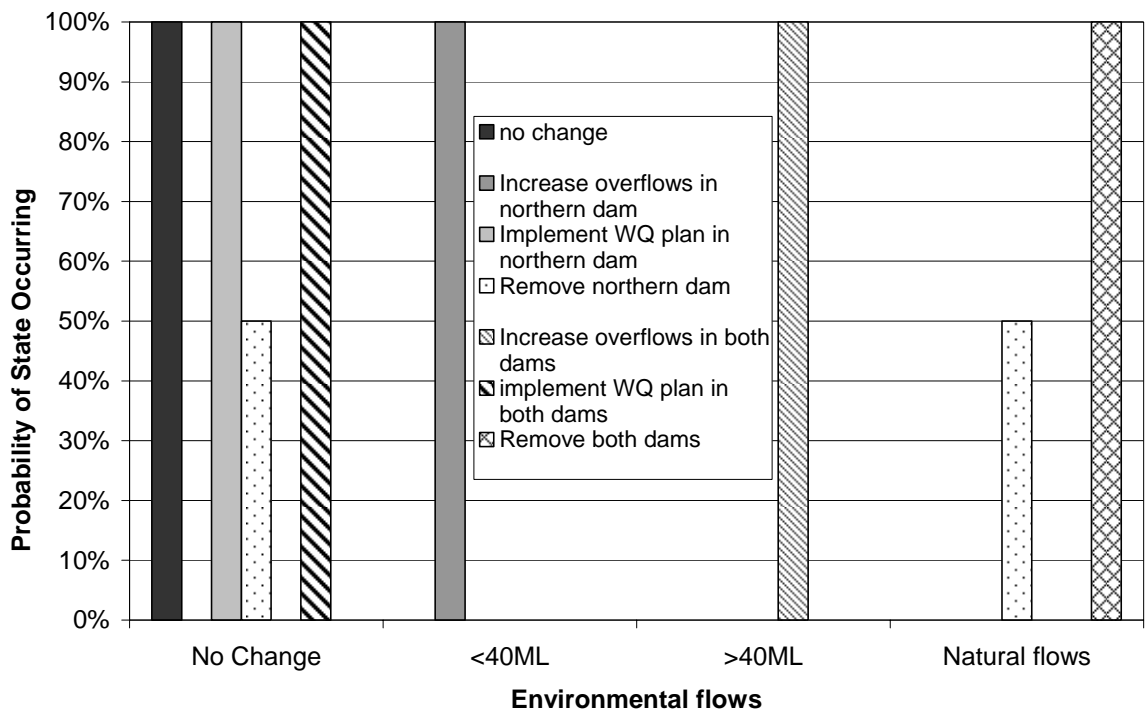


Figure 12. Probability of changes to environmental flows as a result of management of the northern and southern dams.

Table 6. Summary of impacts of northern and southern dam management on likely state values for impacted nodes

	Increase overflows in northern dam	Implement WQ plan in northern dam	Remove northern dam	Increase overflows in both dams	implement WQ plan in both dams	Remove both dams
Algal blooms	small decrease	small decrease	moderate decrease	small decrease	very small increase	moderate decrease
Aquatic fauna	small increase	small decrease	negligible	negligible	small decrease	very small increase
Creek sediments	moderate increase	moderate decrease	large decrease	large increase	large decrease	large decrease
Local Revenue	negligible	negligible	negligible	negligible	negligible	very small increase
Mangroves	large increase	small decrease	very small increase	large increase	moderate decrease	moderate increase
Recreational amenity	very small increase	very small increase	small increase	small increase	negligible	small increase
Saltmarsh	small decrease	moderate decrease	moderate decrease	small decrease	moderate decrease	moderate decrease
Seagrass	negligible	moderate decrease	very small decrease	moderate decrease	moderate decrease	negligible
Total costs	no change	no change	very small decrease	very small decrease	no change	very small decrease
Tourism	negligible	very small increase	very small increase	very small increase	negligible	small increase
Water quality guidelines	large decrease	moderate increase	moderate increase	large decrease	very small increase	small increase
Aboriginal values	moderate increase	moderate increase	large increase	large increase	large increase	large increase
Creek depth	negligible	no change	negligible	negligible	no change	negligible
Creek entrance berm dynamics (breakouts)	no change	large increase	large increase	large increase	large increase	large increase
Creek flushing	moderate increase	no change	small increase	moderate increase	no change	moderate increase
Creek TN	moderate increase	small decrease	very small decrease	moderate increase	moderate increase	small increase
Creek TP	moderate increase	negligible	negligible	moderate increase	moderate increase	small increase
Creek TSS	moderate increase	small decrease	negligible	small increase	small increase	small increase
Disaster cost	no change	no change	moderate decrease	moderate decrease	no change	moderate decrease
Environmental flows	small increase	no change	moderate increase	moderate increase	no change	large increase
Flood risk	no change	no change	small decrease	small decrease	no change	small decrease

Creek sediments (figure 13) are likely to increase due to an increase in dam overflows, however implementing water quality plans or removing dams is likely to decrease creek sediments.

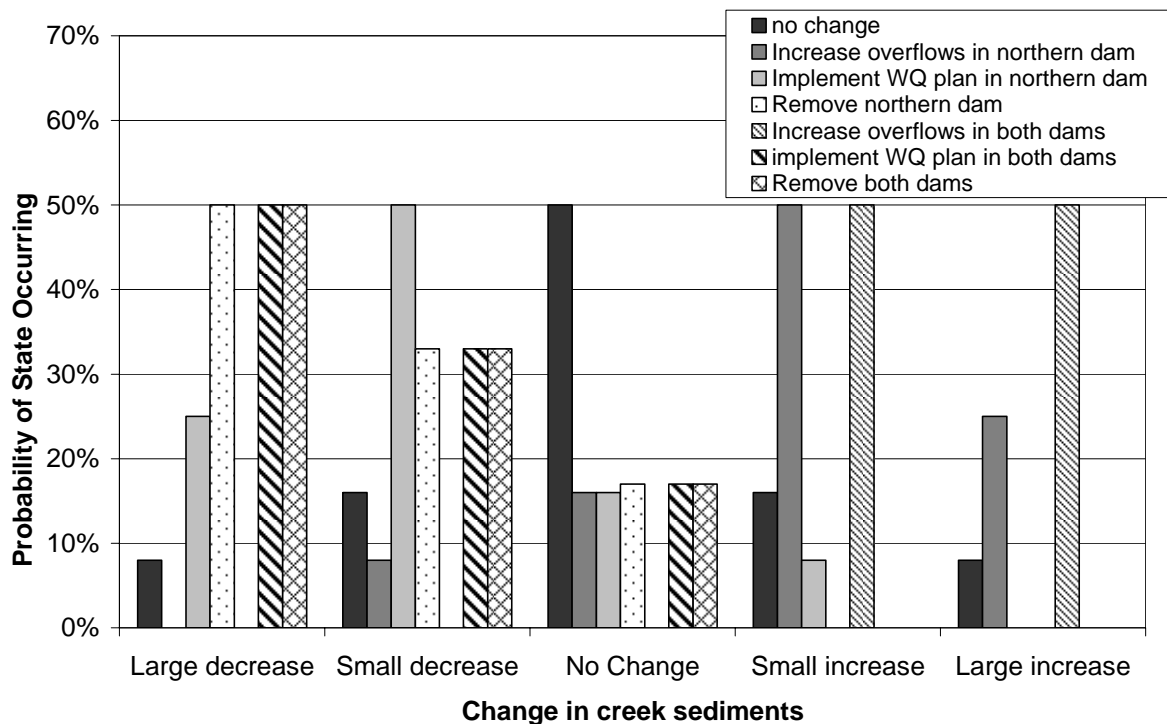


Figure 13. Probability of changes to creek sediments as a result of management of the northern and southern dams.

## 6 DISCUSSION OF THE RESULTS

This Sustainability Assessment report has provided a sample of results for management of vegetation, state forests, agriculture and dams within Dalhousie Creek catchment as well as of the impacts of sea level rise. These options are a small subset of the total number of scenarios which can be considered by the Dalhousie Creek CLAM and as such do not provide conclusive evidence of the 'best' management options available.

These results show:

- vegetation management along the riparian zones and improvements in state forest and agricultural runoff has the potential to reduce creek sediments. Follow-on impacts are seen in water quality guidelines, seagrass and saltmarsh areas.
- sea level rise has some interesting impacts with the small rise predicted for 2050 likely to increase berm height, thereby decreasing the frequency of creek outbreaks. As sea levels rise further by 2100, this impact will be reduced with a likely return to current frequencies.
- small improvements on individual water quality parameters such as TP, TN, TSS and pathogens can combine to give large improvements in compliance with water quality guidelines.

The results shown here as well as the table of data quality provided in Section 3.3 demonstrate some of the features of the data that has been used to underpin the Dalhousie Creek CLAM. In some cases variables do not contain data because there was not any available. These variables are focused around the aquatic populations and include stock harvests. In addition creek sediments, disaster costs, local revenue, recreational amenity total costs and tourism are also considered to have a poor data quality. The CLAM is able to accept updates of

such information over time as it becomes available. This should be considered in conjunction with other identified data collection requirements (see Section 3.3).

## 7 ACKNOWLEDGEMENTS

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## 8 REFERENCES

- Brydon, N., Letcher, R.A., Merritt, W.S., and Ticehurst, J.L. (2007). Coastal Lake Assessment and Management (CLAM) Tool: User Guide. iCAM Technical Report (Version 2). iCAM Technical Report 2007/03, Integrated Catchment Assessment and Management Centre, Australian National University, Canberra.
- DLWC, 1998 Constructed Wetlands Manual. NSW Department of Land and Water Conservation, Sydney.
- DNR Website, Estuary Assessment Framework For Non-Pristine Estuaries, <http://www.dnr.nsw.gov.au/estuaries/inventory/dalhousie.shtml> downloaded 30/3/2007.
- Flametree Ecological Consulting (2006) *Coastal Vegetation of the Bellingen Local Government Area. Mapping Project*. Bellingen Shire Council.
- Gabriel, M. and Willcocks, J. (2004) *Climate change. The challenge for natural resource management*. Qld Department of Natural Resources and Mines.
- Healthy Rivers Commission (2002). "Independent Inquiry into Coastal Lakes", April 2002, [http://www.begavalley.nsw.gov.au/Environment/estuaries/pdfs/Healthy\\_Rivers.pdf](http://www.begavalley.nsw.gov.au/Environment/estuaries/pdfs/Healthy_Rivers.pdf)
- Intergovernmental Panel on Climate Change [IPCC], 2001. Special Report on Emission Scenarios. Nakicenovic, N., Swart, R. (Editors.) Intergovernmental Panel on Climate Change.
- Lawrence, I. and Breen, P. (1998) Design guidelines: Stormwater pollution control ponds and wetlands. Cooperative Research Centre for Freshwater Ecology, Canberra.
- Merritt, W., Brydon, N., Letcher, R., and Ticehurst, J. (2007), Ensuring the sustainability of Coastal Lakes in NSW Northern Rivers: Coastal Lakes Assessment and Management (CLAM) Tool User Workshop (Phase 2), iCAM Technical Report 2007/02, Integrated Catchment Assessment and Management Centre, Australian National University, Canberra.
- NRCMA (downloaded 30/3/2007), [www.northern.cma.nsw.gov.au/pdf/dalhousieck.pdf](http://www.northern.cma.nsw.gov.au/pdf/dalhousieck.pdf).
- Rissik, D., Nelson, P., White, J., Hatfield, E., and Cenedese, S., (2003), Preparation of Sustainability Assessments for Coastal Lakes, Draft project proposal, 2nd December 2003.
- Ticehurst, J.L., Merritt, W., and Rissik, D. (2006), Coastal Lakes Assessment and Management Tool: Application and tailoring workshop, iCAM Technical Report 2006/01, Integrated Catchment Assessment and Management Centre, Australian National University, Canberra

Ticehurst, J.L. Newham, L.H. T., Rissik, D., Letcher, R.A. and Jakeman A.J. (2007), A Bayesian network approach for assessing the sustainability of coastal lakes, *Environmental Modelling and Software*, 22(8):1129-1139.

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

**APPENDIX 1. SUMMARY OF NODES IN THE DALHOUSIE CREEK CLAM TOOL**

Node	Description	Output States	Units
Aboriginal values	Includes physical heritage, landscape significance and natural resource managements	Large loss, small loss, no change, small increase, large increase	
Algal blooms	Change in algal populations resulting from inputs of sediments and nutrients to the creek	large decrease, small decrease, no change, small increase, large increase	
Aquatic fauna	Change in the numbers and health of creek fauna	large decrease, small decrease, no change, small increase, large increase	
Area of native vegetation	Changes in area of native vegetation as a result of land use and/or management	Decrease, no change, <5% increase, 5-10% increase, >10% increase	%
Catchment population	Changes in population resulting from potential development planning changes in existing urban areas	decrease, no change, small increase ( $\leq 25\%$ ), large increase ( $>25\%$ )	%
Community complaints	Number of complaints received by council and government agencies	decrease in complaints, no change, increase in complaints	
Creek depth	Expected median creek depth (m) in any given year	<0.5, 0.5-1.5, 1.5-2.75, >2.75	metres
Creek entrance berm dynamics	Height of berm will control the level at which the creek opens in response to fresh water flows from the catchment, and salt water from the ocean	Decrease in creek breakout events, No Change, Increase in creek breakout events	
Creek flushing	Changes in the hydraulic residence time of the water in the creek	decrease, no change, small increase, large increase	time
Creek pathogens	Delivery of pathogens to creek in CFU/100mL of faecal coliforms from runoff and direct delivery of manure to stream.	<14, 14-75, 75-150, 150-300, 300-500, 500-1000, >1000	CFU/100mL
Creek sediments	Accumulation of sediment loads in the creek as a result of land use and management	large decrease, small decrease, no change, small increase, large increase	
Creek TN	Total nitrogen (TN) loads to creek	<500, 500-800, 800-1100, 1100-1400, >1400	kg/yr
Creek TP	Total phosphorus (TP) loads to creek	<100, 100-150, 150-200, 200-300, >300	kg/yr
Creek TSS	Total suspended solids (TSS) loads to creek	<2000, 2000-5000, 5000-8000, 8000-12000, >12000	kg/yr
Disaster costs	Qualitative estimate of the impacts of natural disasters. Currently only accounts for the impact of flooding impacted upon by flood risk	decrease, no change, increase	

Domestic pets	Number of domestic pets	decrease, no change, <25% increase, >25% increase	%
Environmental flows	Flows of water from the two dams to the creek to maintain and enhance sustainable ecological function	no change, <40ML, >40ML, natural flows	ML
Flood risk	Extent and likelihood of flooding to low lying properties resulting from changes in creek and catchment management	decrease in flood risk, no change, increase in flood risk	
Local revenue	Income	decrease, no change, increase	\$
Mangroves	Change in the area of creek mangroves	large decrease, small decrease, no change, small increase, large increase	area
Seabirds and shorebirds	Impacts on migratory and resident seabirds and shorebirds dependent on creek and entrance area	large decrease, small decrease, no change, small increase, large increase	numbers
Pet management	Reflects the community's current understanding about responsible pet control, as it relates to the health of native fauna	decrease in impact of pets, no change, increase in impact of pets	
Recreational amenity	Impacts on tourism from changes in management of creek and catchment	large decrease, small decrease, no change, small increase, large increase	
Saltmarsh	Change in the area of creek saltmarsh	large decrease, small decrease, no change, small increase, large increase	area
Seagrass	Change in the area of creek seagrass	large decrease, small decrease, no change, small increase, large increase	area
Stock harvest	Changes in the stock catch resulting from changes in fishing management	decrease harvest, no change, increase harvest	
Terrestrial fauna	Change in numbers and health of terrestrial fauna in catchment and around creek	large decrease, no change, large increase	
Total costs	Total costs as a result of disaster costs and community complaints	Decrease, No change, Increase	
Tourism	Qualitative impacts on tourism from changes in recreational amenity	large decrease, small decrease, no change, small increase, large increase	
Water quality guidelines	Qualitative measurement of compliance with water quality guidelines	large decrease, small decrease, no change, small increase, large increase	

**APPENDIX 2. ADDITIONAL SCENARIO GROUPS AVAILABLE IN THE DALHOUSIE CREEK CLAM TOOL**

- Coastal processes
- Commercial fishing
- Community engagement
- Existing development
- Power line
- Railway line

**Coastal processes**

Sea level is predicted to rise in line with climate change. Associated likely impacts on beaches are poorly understood but in general it is considered that beach berms may either rise or fall over the medium to long term depending on beach alignment processes and longshore sand transport patterns.

**Commercial fishing**

This scenario examines the impact of continuing or removing commercial fishing from the creek. Commercial and recreational fishing are carried out in the creek. All licensed fishers in the Estuary General Fishery Zone 3 are eligible to harvest in the creek, but only 3 or 4 do so on a regular basis (Geoff Blackburn, Pers. Comm.).

**Community engagement**

This scenario examines the impact of the community accepting all recommended options with enthusiasm. This would be expressed in the speed and effectiveness of implementation. Little scientific information is available for the creek and catchment to underpin management. However, the CLAM project is the first step in a formalised management process that would seek to obtain more accurate and precise information with which to build on the CLAM, and proceed with a sustainable management approach in the meantime.

**Existing development**

This scenario examines Best-Practice options for managing two main pollutant sources

- for stormwater: all best practice "Urban Controls" options under the general heading of Water Sensitive Design, including treatment systems (e.g. swales, wetlands) and buffer zones;
- for onsite systems, compliance with Council/State Government policies (e.g. Aerated Wastewater Treatment Systems, reed-beds, buffers)

**Power line**

This scenario examines the management of the easement for overhead Power line through State Forest area. The Power line easement occupies about 8ha in two subcatchments, and is marked by bare eroded soils, soil heaps and lack of vegetation in places, with additional observed impacts from trail-bikes. The utility company, which licenses the easement from Forests NSW, would be encouraged to undertake a more sustainable management regime, focusing on revegetation with suitable low-growing species appropriate for planting beneath the lines.

**Railway line**

This scenario examines the impact of a Weed Control Plan by State Rail for the rail line easement with full revegetation with appropriate native plants and ongoing management. The Dalhousie Creek Project Reference Group has identified weeds along the line and spreading from the railway as a potential damaging impact on native vegetation in the vicinity of the creek.