LAKE CURRIMUNDI DYNAMICS STUDY

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PREPARED BY:

R. TOMLINSON

P. WILLIAMS

R. RICHARDS

A. WEIGAND

T. SCHLACHER

V. BUTTERWORTH

N. GAFFET

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<table>
<tr>
<td rowspan="4">GRIFFITH CENTRE FOR COASTAL MANAGEMENT

Griffith University Gold Coast
Parklands Drive
SOUTHPORT QLD 4215

Telephone (07) 55528506
Facsimile (07) 55528067
www.griffith.edu.au/coastal-management</td>
<td>Document: Griffith Centre for Coastal Management Research Report No. 75</td>
</tr>
<tr><td>Project: Lake Currimundi Dynamics Study</td></tr>
<tr><td>Title: Lake Currimundi Dynamics Study Final Report Volume 1
Project Leader: Professor Rodger Tomlinson
Author(s): Rodger Tomlinson
Peta Williams
Russell Richards
Aaron Weigand
Thomas Schlacher
Vern Butterworth
Nathalie Gaffet</td></tr>
<tr><td>Sponsoring Organisation: Sunshine Coast Regional Council (formerly Caloundra City Council)
Contact: Denise Johnson/Graham Webb</td></tr>
<tr><td colspan="2">Synopsis: This report presents the findings and recommendations of the Lake Currimundi Dynamics Study. This study has addressed a range of ecosystem processes and management options for the lake. The approach adopted has been to address processes and issues in the context of an adaptive management framework.</td></tr>
<tr><td colspan="2">Keywords: Lake Currimundi, adaptive management plan, midge, water quality, stream bank erosion, entrance dynamics, hydrodynamic modelling, berm, coastal processes, community engagement.</td></tr>
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EXECUTIVE SUMMARY

The community of Currimundi continue to express concern over a range of issues affecting the Lake Currimundi system, and a study has been undertaken with the aim of developing a better understanding of:- the interrelationships between various ecosystem processes; the impacts of urbanisation and past, present and future management actions.

The issues identified have included:

- Bank erosion along the full length of the lake
- Front beach erosion
- Increase in tidal prism
- Silt build-up
- Midge problems since 1960s – ideal habitat since 2003
- Vegetation change
- Infrastructure below flood level
- Anecdotal view that ICOLL open about 90% of time since 1988
- Concern over storm water inputs and sewage overflows lake is going brown – tannin or coffee rock or construction sediment
- Algae – from offshore or from lake and die-off on opening
- There are major catchment wide problems – MMTC and CAMCOS transport corridor construction
- Problems with Acid Sulphate Soils (ASS) and pipe corrosion
- Concern over high Faecal Coliforms at times
- Need values analysis
- Water quality generally
- Flooding.

This study has examined lake dynamics and has attempted to provide an integrated overview by consolidating community concerns under the following headings:

- Biting Midge Nuisance
- Bank Erosion
- Lake water quality
- Tidal Hydrodynamics and Entrance Behaviour
- Influence of Lake Kawana

The study area is shown below and encompasses: Lake Currimundi and its tributaries; Tokara, Pangali and Baroona canals; Lake Kawana, only in regard to the extent to which the flow and water quality exchanges with Lake Currimundi; the beaches adjacent to the Lake entrance, and the broader Currimundi catchment, only in regard to changes which influence Lake hydrology and catchment pollutant loads.

Study Area (Source: Google Earth)

The study addresses the range of issues already identified and utilises existing information as well as biophysical data obtained during the course of the study. The study establishes a framework for an adaptive management approach to lake management and sets out an implementation plan which is flexible and can be effective immediately, but which can be developed into a more sophisticated system with future budget allocations. This adaptive management framework includes monitoring systems and modelling tools.

The key findings of the study are summarised under the broad heading defined above, as follows

Biting Midge

It is unlikely that the recent dramatic increase in biting midge populations in Lake Currimundi could have been foreseen. The slow change to the natural cycle of this ICOLL occurred over several decades and it wasn't until the lake had remained open for several years that the midge became apparent. It is also highly likely that the biting midge have always been present in this system and that the natural ICOLL cycle kept their populations at levels that were barely perceptible. Other changes in the catchment that are the result of increasing urban development may have also been beneficial to the midge.

Attempts to minimise the abundance of biting midge have been most successful where the natural cycle of the ICOLL has been replicated through well timed closures. Other measures to vary the elevation and composition of the larval intertidal habitats have also had a degree of success.

Monitoring and study of the biting midge populations must continue so that the understanding of this species is improved and to guide future control programs. Management of the lake and surrounds must be mindful of the existence of the midge and wherever possible public works and interventions should aim to minimise its abundance and impact on adjoining urban areas.

If the lake closes naturally then the time it is allowed to remain closed should take into account the midge lifecycle. Matters to be considered would include recent larval densities, typical adult midge abundance during that time of year, water quality impacts, risks of upstream flooding etc. In general terms it should be allowed to remain closed for as long as possible. A trigger for opening under these circumstances would be an increase in water level to 0.9m AHD. At this point bank instability has been observed historically and the design freeboard in Lake Kawana is reached.

Any proposed works in the intertidal zone should take into account the potential biting midge larval habitat. Generally intertidal beaches should be steeper, flat beaches should be lower in elevation and high levels of organic matter should be avoided so that beaches are less suitable as larval habitat. Engineering and environmental constraints would also need to be considered. Any proposals that increases the tidal range and as a consequence increase the intertidal beach larval habitat should be avoided.

Bank erosion

From community input and previous studies, it is clear that bank erosion has been ongoing for many decades either due to natural causes or through modification to the Lake as a result of urbanisation. It is well documented that natural systems suffer from bank erosion due to stream meandering, intermittent opening and closing, and scour due to extreme flooding events. However, the concerns of the community over the current situation require an identification of causes for erosion under the modified state of the lake. Unfortunately no single cause has been identified through the review of earlier studies or from comments by the community. The cause of the erosion is most likely a combination of a number of factors including those identified by Witheridge (2006):

- inappropriate vegetation
- exposure of dispersive sub soil
- redirection of flow at key locations
- recreational impacts – boating and infrastructure
- instability with soil saturation when water level is elevated

Although the development in the catchment and the transition of the Lake from an ICOLL to an estuary is no doubt causing increased flows, the main issues are that the banks have been modified from their natural state for recreational and visual amenity purposes, and that there is a significant level of boating activity.

In general the issue of bank erosion is one of that can benefit from modification to riparian management practices, but which will also be reactive to other Lake management strategies dealing with water quality and biting midge. Controls of boating activities will also provide relief from persistent erosion. Active involvement of community groups in monitoring and reporting bank stability issues is seen as important for effective management.

Water Quality

The study brought together some ad hoc measurements and observations about water quality; an analysis of both the Sunshine Coast Regional Council (SCRC) and Currimundi Catchment Care Group (CCCG) water quality data sets and some intensive measurement taken during the major field exercise in June 2008.

The main findings of the analysis of long term data identifies that:

- Conductivity / Salinity – varies between ‘seawater’ and ‘freshwater’ levels
- Turbidity – frequent spikes (rainfall)
- DO – consistently low
- Faecal coliforms – mostly low, occasional spike
- Nitrogen – consistently high
- Phosphorus – occasional spikes
- Suspended sediment – consistently high

The coincidental commencement of the Lake Kawana pumping and the major dredging of the sand plug in the entrance in 2004 – 2005 was examined and it was noted that after 2005 there was a:

- Increase in DO and conductivity at most sites
- Decrease in suspended sediment at upstream sites
- No decrease in nitrogen (NH3, NOx, Ntot)

From an assessment of the data from SCRC and CCCG it was also concluded that the bulk statistics of both sets of data, for all water quality indicators, are broadly similar.

The intensive data collection in June 2008 enabled an assessment of water quality against guidelines, although it is noted that this monitoring followed an extreme rainfall event. Key findings were:

- Nitrogen components – much higher than guidelines
- Chlorophyll-*a* – strong exceedance
- Turbidity - exceedance
- Phosphate – generally compliant
- Total phosphate - high exceedance based on Caloundra-specific WQOs but not EPA guidelines
- Exceedance higher in most cases for Caloundra-specific than EPA (phosphate excepted)

The generalised additive modelling (GAM) undertaken here on all available data for Lake Currimundi has highlighted some potentially important temporal and environmental characteristics:

Tidal Hydrodynamics and entrance behaviour

The physical process measurement exercises have demonstrated a number of key features of the Lake Currimundi system, namely

- In general when the entrance is "closed' or "nearly-closed", only ocean tides higher than MHWN have any significant impact on the lake.
- During near-closure, the tidal range will not vary in the lake much more than around 0.3m.
- Following a major entrance opening (during a spring tide) the lake responds by establishing a strong tidal flow for a period of days with water levels being elevated above that of the near-closed condition.
- The impact of this strong tidal flow gradually diminishes with recovery back to a closed condition (as indicated by salinity levels or a reduction in flow velocity and tidal range) taking of the order of 40 days in the uppermost section of Tokara Canal. Recovery is much quicker in the lower reaches of the Lake.
- Flood tides are short relative to the ebb tide compounded by the nett outflow from Lake Kawana of 68ML/day.
- Flood tide velocities are much higher than ebb tide velocities resulting in rapid infilling of the entrance with marine sand.
- There is a significant phase lag between ocean tides and tides within the Lake
- There is little or no phase lag between locations near the entrance and in the uppermost section of the Lake system

The Lake hydrodynamics correspond with that of a classical tidal lake where tidal flow is controlled by the constriction at the entrance. The extent to which tides penetrate the lake will depend on the volume of sand in the entrance, and there is little variation in tidal behaviour throughout the lake system. The hydrodynamic model provides a tool to examine over time the response of the system to a mechanical opening, and it is recommended that the model be calibrated for a number of such events. Given that the variability and complexity of entrance opening characteristics, it is not realistic to use the model to predict all individual event possibilities. Considerably higher levels of model sophistication would be needed to simulate the sediment transport processes associated with this closure. The model however will be able to simulate the impacts of any modification to the Lake Kawana pumping regime or the proposed connection to the top of Tokara Canal.

The preferred mechanism for management of water level and tidal exchange with the ocean is to artificially open or close the entrance and to maintain the location of entrance channel on the northern side of the lake. It has been found that this is the dominant location under the influence of littoral processes and minimises the risk of scour undermining build assets on the southern side. The presence of indurated sand banks on the northern side provides a natural defence against scour of the northern banks.

Influence of Lake Kawana

The impact of the lake Kawana connection is twofold – the daily pumped discharge acts to reduce the flood tide velocities and hence will reduce the infilling rate for marine sand at the entrance; but during very high spring tides, or following an entrance opening the tidal connection to Lake Kawana will result in an increase in tidal exchange (and hence tidal velocities and sediment transport) until the water level falls to around 0.4m in the Lake. This has the effect of encouraging rapid infilling immediately following an opening (or a high spring tide) which will accelerate the attenuation of the tidal signal and the reduction in entrance conveyance back to a new level in equilibrium with the pumped base flow from Kawana.

Consideration has been given to the modification of the Lake Kawana weir and further inter-connection between Lake Kawana and Lake Currimundi to enhance water quality and other outcomes. Although these options have not been examined in detail in terms of design and cost, it is the view of the expert panel and the research team that there are positive benefits from the net discharge from the Mooloolah River and the subsequent inter-connection to Lake Currimundi. The critical issue is that the Kawana and Currimundi system must now be considered as a single managed environment and strategies must be developed which reflect the inter-connectedness.

Adaptive Management Framework

The key objective of this study was to develop a broad holistic understanding of the various ecosystem processes in Lake Currimundi and their inter-relationships, and to integrate this understanding into a management strategy which accounted for environmental, economic and social issues. An over-riding consideration has been for the management strategy to be adaptive. Management of the lake in the past has involved the mechanical opening or closing of the entrance in response to water quality, biting midge or coastal erosion issues. Since the development of Lake Kawana, the lake dynamics have changed, but another option for management has presented itself (i.e. pumped discharge through the lake system).

In general, the management actions taken have been reactive, but have also been adaptive, with common sense actions being taken. A desired outcome from this study is that these actions be placed within an Adaptive Management Framework, allowing for a more finely balanced system in the future.

In order to effectively implement an AMF for Lake Currimundi, the following key components need to be in place.

- A protocol or guideline
- A monitoring program
- A capacity to model or simulate system response to proposed action
- A workable cost-effective suite of management options
- A decision making process engaging key stakeholders
- A commitment to continue adapting

AMF Protocol

The Lake and Estuary Risk and Operational Management Protocol (LEROMP) is a document prepared by Council officers some time ago. It addresses all of the key elements of an AMF and one of the main findings of this study is that the LEROMP should continue to be used as the framework for adaptive management. Particular study findings and recommendations should be integrated into the LEROMP either as new elements or as updates to existing elements

Monitoring Programs

One of the tasks in the study was to specify a range of monitoring programs covering water quality and physical processes. As the study progressed, the requirements for monitoring have been simplified.

- The tidal hydrodynamics measurements and modelling have indicated that there is only a need for one tide gauge to be installed. It would also be helpful if measurements were also taken of Lake Kawana water levels, at least until a better understanding of the inter-connection is gained.
- Continuous velocity measurement is not required, however, event specific monitoring would be beneficial.
- Monitoring and study of the biting midge populations must continue so that the understanding of this species is improved and to guide future control programs.

Management of the lake and surrounds must be mindful of the existence of the midge and wherever possible public works and interventions should aim to minimise its abundance and impact on adjoining urban areas.

- Monitoring of water quality is critical for a highly urbanized system such as Currimundi. Both baseline conditions and event impacts should be targeted, but given the current cost of water quality sampling and analysis, a finding of the study has been that a more cost-effective approach would be to integrate the Council and community based monitoring programs. The current sampling regime is adequate with a recommendation that chlorophyll-*a* be included.
- Monitoring of other aspects of the lake environment such as bank erosion and fish populations is important, and again is an area where involvement of community-based programs supported by regular surveys by University students should be utilized.
- The principal control on tidal flow into the lake is the level of constriction at the entrance. Routine identification of the size and location of the entrance channel over time will enable relationships between environmental forcing (storms, tides) and entrance configuration to be developed enhancing the refinement of management strategies.
- Another control on water quality is the volume of new water introduced into Currimundi via the connection with Lake Kawana. Pumped flow rates should be monitored in real time.

Monitored data should be used to develop models of various features in the system and to determine management trigger points.

Modelling

Given the high degree of variability in natural systems such as Lake Currimundi, it is nearly impossible to quantitatively model in detail all of the processes and inter-relationships that exist between the various parameters and processes. However, within the adaptive management framework it is possible to build up a suite of conceptual, empirical, statistical and deterministic models, which over time will define the character of the lake.

For example, the impact of minor water level variations (eg due to rainfall, partial closures etc) on biting midge is unknown. Whilst there is a conceptual model suggesting a certain relationship, by undertaking water level monitoring and correlating these data with midge population data, a trend could be established. Similarly, the observations of wave height leading to a breaching of the berm should be recorded allowing an empirical model of ideal berm height to be developed.

The hydrodynamic model developed for this study can be used in a number of ways. As discussed earlier the model can be run again and calibrated with specific field experimental data during a number of entrance openings and closings. Over time a coarse relationship can be developed for the volume of sand removed versus the duration of entrance opening for example. The model can also be used to simulate the impact on water quality of a connection from Lake Kawana to the end of Tokara Canal, or the impact of increasing the pumped discharge rate through Lake Kawana. Other operational information can also be extracted from the model, such as the total volume of tidal exchange across the weir during an entrance opening event.

These “models” can be incorporated into the AMF as part of the overall information gathering and analysis.

Management Options
The report findings indicate the current management strategy of artificial opening and closing the lake entrance is the most cost-effective, efficient and flexible method of achieving water quality and other environmental objectives. Other options considered worth implementing are the manipulation of the inter-connections with Lake Kawana. Under the AMF it is important to allow operational flexibility with management options. For example, control activities will become more refined over time as knowledge of the midge lifecycle and understanding of the lake dynamics improves. These control activities must also take into account the wider impact that they may have on the Lake environment and the species therein. The lake water levels should be investigated with a view to limiting larval midge survival. For example the strategically timed variation of discharges from Lake Kawana to maintain higher water levels may impact on larval midge.

Another over-riding management constraint is that interventions should be limited to a minimal level, and that the AMF process be used to establish what level is appropriate.

A key component of any AMF is the engagement and involvement of the community in decision making. There has been a very significant contribution from the community during this study through the various community consultation activities including environmental values assessment. The Lake Currimundi community is an active and willing partner in lake management. The role of the community in the monitoring and modelling components of the AMF has been addressed elsewhere. The role of the community in advising and endorsing Council action can be facilitated through a steering committee responsible for the implementation of the AMF.

Commitment
Finally the AMF process requires an on-going commitment to regular monitoring and modelling activities, flexibility in management operations, reliance on the community to support the process, and more active engagement of the expertise within SCRC in the determination of relationships and management responses. These activities require a commitment from SCRC to appropriately resource and support the AMF process.

Other Issues

Finally, throughout this study, a number of key issues have been raised which although falling outside the scope of the study, have a direct influence on future management of the lake. These are regional issues which fall within the broad areas of catchment management, beach management and climate change adaptation.

In particular, Lake Currimundi cannot be seen in isolation from Lake Kawana, the Mooloolah River system and the broader urban catchments to the west. Regional water quality and ecosystem objectives need to be set, and given there will be very limited capacity to adequately manage the inter-connectedness of the system in the future the following is recommended.

The entrance to Lake Currimundi cannot be seen in isolation from the adjacent beaches and the impact of climate variability. Any entrance management option such as the construction of a seawall, must be considered as part of an overall shoreline erosion management plan.

Finally, the biggest challenge for the future will be to adapt to climate change. Lake Currimundi and the adjacent areas are extremely vulnerable to accelerating means sea level rise, and intensification of storms, whether manifested as more extreme beach erosion or larger floods from higher freshwater run-off. Adaptation strategies are being considered across the South East Queensland region, as are more targeted studies such as storm surge projections.

Recommendations

The following table sets out the recommendations detailed in Chapter 11. These recommendations address actions which can be taken by SCRC, or in partnership with other stakeholders such as the Currimundi Catchment Care group.

The recommendations are grouped based on the nature of the works required to implement them, as follows:

- Policy
- Capital Works
- Operational Works
- Design and Management Guidelines
- Natural Area Management
- Community Engagement
- Resourcing
- Further Studies

Recommendation Grouping	Recommendation Number (Chpt. 11)	RECOMMENDATION
Policy	8	*Incorporate the inter-connectedness of the Kawana and Currimundi systems into environmental management and planning.*
	18	*Use SCRC's Lake and Estuary Risk and Operational Management Protocol (LEROMP) as the foundation for subsequent adaptive responses.*
	26	*Implement a catchment-wide pollutant source control program to limit the impact of urbanisation.*
	28	Develop a strategy for engagement with the community leading to a climate change adaptation strategy.
Capital Works	5	*Undertake no structural modification to Lake Kawana Weir.*
	6	*Proceed with the proposed inter-connection to the end of Tokara Canal.*
Operational Works	4	*Direct Council-based water quality effort towards event monitoring with intensive monitoring prior to and after planned entrance opening and closing activities.*
	11	*Continue with the annual late winter/spring closure of Lake Currimundi if winter larval densities indicate that adult populations during spring will be unacceptably high.*
	13	*Undertake hydrodynamic monitoring and modelling for future events to build a matrix of calibrated outputs for inclusion in the AMF.*
	14	*Establish a tide gauge at the Nicklin Way bridge with data logging and telemetering capability for an alarm indicating elevated water level. Consideration could also be given to co-locate a rainfall gauge to enhance understanding of water quality dynamics.*
	15	*Establish a remote camera system for entrance channel monitoring.*
Design and Management Guidelines	2	*Include Chlorophyll-a, and coincident environmental parameters such as wind speed and direction, entrance condition and rainfall in both Council and community group water quality monitoring.*
	7	*Routine monitoring of water quality throughout the system should be focussed on defining the changes in water quality which may occur as a result of increasing urban development in the catchment.*
	10	*Develop and implement a boat wash management strategy.*
	12	*Limit lake-side beach elevation to less than 0.6m AHD.*
	16	*Limit the migration of the entrance channel to the northern half of the lake mouth through a berm management program.*

Recommendation Grouping	Recommendation Number (Chpt. 11)	RECOMMENDATION
	17	*Maintain a berm height of 2m above spring high tide level, and a width of 50m at that level.*
	23	*Limit the extent of mechanical entrance opening to the prevention of flooding and the maintenance of a prescribed maximum water level in the lake which is compatible with foreshore amenity and midge control.*
	27	*Undertake a Shoreline Erosion Management Plan including entrance stability options.*
Natural Area Management	9	*Develop a lake foreshore erosion management plan including riparian vegetation rehabilitation and structural bank stabilisation where appropriate.*
Resourcing	25	*Council commits resources and provides a mandate for SCRC officers to implement the AMF thereby ensuring its success.*
Community Engagement	1	*Integrate the water quality monitoring program undertaken by the Currimundi Catchment Care Group into the overall monitoring for the adaptive management framework.*
	3	*Encourage and support community-based water quality monitoring if appropriate to provide baseline information.*
	20	*Include community involvement in monitoring of bank erosion and environmental and other causal factors. This information should be integrated into operation of the AMF.*
	24	*Empower a community steering group to support Council's decision making processes in terms of lake and entrance management.*
Further Studies	19	*Enhance the adaptive management framework (AMF) approach currently being used.*
	21	*Establish a central database into which remotely sensed and transmitted data such as tide level as well as routinely acquired data such as water quality can be stored and analysed. These data should be complemented by meteorological, hydrological and wave climate information.*
	22	*Ensure that data is not only collected but analysed with the aim of establishing a range of conceptual, empirical and computational models.*

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CHAPTER 1 - INTRODUCTION

1.1 INTRODUCTION

The Sunshine Coast is experiencing unprecedented growth and is one of the fastest growing cities in Australia. This growth will place significant pressure on the city's waterways unless managed appropriately. The region's catchments and their associated waterways have high environmental, social, recreational and economic value as well as regional, national and international significance and provide a range of opportunities and benefits for residents and visiting tourists.

As a feature of the region's natural environment, Lake Currimundi is a coastal lagoon which is generally open to the ocean. Development in the catchment has seen the construction in the 1980s and 1990s of three canals which now form part of the tidal waterway of the Lake. The Lake has also recently been connected to the artificial Lake Kawana via a weir set at 0.6 AHD. In order to develop an integrated management plan for the Lake and its waterways, a study of the Lake dynamics was proposed, with the Griffith Centre for Coastal Management being commissioned to undertake the study. This project was commenced prior to the recent amalgamation of local authorities under the auspices of the Caloundra City Council (CCC), which is now part of the Sunshine Coast Regional Council (SCRC). Throughout this report the client will be referred to as SCRC.

1.2 OBJECTIVES

The aim of the study is to develop a knowledge system which can form the basis of an adaptive management approach to Lake ecosystem health. The objectives of the study are to:

- Develop conceptual models of key features of lake dynamics.
- Develop a cost-effective model(s) for estimating and predicting lake hydrodynamic, water quality and sedimentary regimes
- Establish a monitoring system for water quality and tidal parameters which is flexible enough to define both the quasi-steady state conditions under various entrance opening regimes and the changes which occur during freshwater flood events
- Deliver a communication strategy for the community
- Develop a set of community sanctioned triple bottom line values on which to base the management actions
- Identify legislative constraints such as permits and approvals
- Develop an adaptive management implementation program which integrates the monitoring, modelling and management actions into a responsive action plan.
- Place in context of coastal processes

A glossary of terms used in the report is given in Volume 2 – Appendix 1.

1.3 SCOPE

The study area is shown in Figure 1 and encompasses:

- Lake Currimundi and its tributaries;
- Tokara, Pangali and Baroona canals;
- Lake Kawana, only in regard to the extent to which the flow and water quality exchanges with Lake Currimundi;
- the beaches adjacent to the Lake entrance, and
- the broader Currimundi catchment, only in regard to changes which influence Lake hydrology and catchment pollutant loads.

Figure 1: Study Area (Source: Google Earth)

The study addresses a range of issues already identified by Council officers and other stakeholders as set out in Volume 2 - Appendix 2 and utilises existing information as well as biophysical data obtained during the course of the study. Mechanisms for integrating the monitoring systems identified during the study with Council's existing resources are addressed and maintenance and operational issues discussed.

The study utilises models appropriate to the need to: develop an adaptive management framework; have low set-up cost; and are able to be operated into the future by Council officers or other organisations contracted for that purpose.

The study establishes a framework for an adaptive management approach to lake management and sets out an implementation plan which is flexible and can be effective immediately, but which can be developed into a more sophisticated system with future budget allocations.

1.4 TASKS

A number of tasks were identified in the original project brief as paraphrased in Volume 2 - Appendix 3. The tasks were as follows:

a. Analysis of existing water quality data and correlation with environmental parameters and system behaviour
b. Conceptual Models Workshop
c. Monitoring system
d. Triple Bottom Line (Environment, Social and Economic) Values Assessment and community engagement program
e. Hydrodynamic Advection - Dispersion model
f. Entrance options assessment and Cost/Benefit Analysis
g. Lake Kawana inter-connection options assessment and Cost/Benefit Analysis
h. Implementation plan for Adaptive Management Framework

1.5 REPORT STRUCTURE

The report will provide a detailed description of the various activities undertaken during the project. Whilst all of the proposed tasks have been addressed, not all activities have been undertaken in the same format as listed in the Project Brief. Also, a number of activities not originally proposed have been addressed in response to changes in emphasis for the project following broader stakeholder engagement. These include the issues of bank erosion and biting midge. A rationale for any modification to the original project brief will be given where appropriate in the report. Consequently the report has been structured in the following order.

Chapter 1: Introduction - presents the proposed work plan and a background and overview of the key issues which lead to the commissioning of the study.

Chapter 2: Community Engagement - presents the findings of the various community consultation activities and the triple bottom line assessment.

Chapter3: Bank Erosion - deals with the persistent bank erosion that is of major concern for the community. Bank stabilisation options are presented and recommendations made.

Chapter 4: Biting Midge - has been prepared by Vern Butterworth from the Sunshine Coast Regional Council and presents the results of field monitoring of midge populations and trials of management options.

Chapter 5: Water Quality – has been prepared by Aaron Weigand and Thomas Schlacher from the University of the Sunshine Coast and presents the results of the long term water quality sampling carried out by both the Council and the Currimundi

Catchment Care Group. The results of the detailed field exercise in 2008 are also presented.

Chapter 6: Water Quality Dynamics - presents the results of a generalised model analysis of the water quality data and other environmental parameters. GAMS models provide an insight into the relationship between various water quality and environmental variables leading to useable management outcomes.

Chapter 7: Lake Hydrodynamics - presents the result of the field data collection exercises held in 2007 and 2008 which focused on the physical characteristics of the system. Computational modelling results are also presented.

Chapter 8: Entrance Options - presents an analysis of the pros and cons of entrance management strategies as they relate to management of the lake and the adjacent beach foreshore.

Chapter 9: Lake Kawana Weir - briefly addresses the role that the interconnections between Lake Kawana and Lake Currimundi have on water quality in the Currimundi system.

Chapter 10: Adaptive Management Framework - briefly introduces the LEROMP as a form of AMF and demonstrates the way in which the LEROMP can be enhanced through the outcomes of this study.

Chapter 11: Summary of Findings and Recommendations - brings together the various study components and previous work and makes a number of recommendations for more effective lake management.

1.6 BACKGROUND

The following overview of previous studies and stakeholder issues is taken from the report to Council by Tomlinson (2006).

1.6.1 Introduction

In recent years, there has been growing community concern over the state of Lake Currimundi, and the condition of the entrance. These concerns have primarily focused on biting midge problems, water quality, entrance management and bank erosion. Also looming large in the mind of the community is the impact of the connection of the artificial Lake Kawana into Currimundi. Before appropriate management strategies can be adopted for the lake, it is important to understand the dynamics of the lake and the changes that have occurred over time. The following sections will address: a broad context for lake dynamics; a more detailed assessment of the key issues; an overview summary of the inter-relationships between various factors creating community concern; and a process for moving forward in developing an appropriate management strategy.

Historically, Currimundi has been functioning as an Intermittently Open and Closed Lake and Lagoon (ICOLL). In its natural state an ICOLL will generally be closed to the ocean during periods of low freshwater input or high sediment movement on the beach. The ICOLL will open in response to elevation of the lake water level due to flooding or due to a major storm erosion event. The ICOLL ecosystem establishes a natural rhythm of intermittent flushing and quasi-still water conditions.

ICOLLs are quite common in NSW, but the small lakes such as Currimundi and Tooway on the Sunshine Coast are representative of this type of coastal system in Queensland. There existence is probably due to a unique combination of rainfall, catchment configuration and littoral beach processes.

Prior to the 1950s, Currimundi was in a relatively natural state by all accounts, and would have on average been semi-closed with a low flow tidal channel connecting the lake to the ocean through a wide sand berm at around R.L.3m. Under these circumstances, the water level would be stable and vegetation and aquatic fauna would have been established to suit these conditions. The occasional breakthrough and flushing of the lake would have disrupted these conditions for a short time, but the semi-closed state would have re-established rapidly.

In terms of the management of the current day lake, it is not particularly helpful to consider this natural state as an objective, because over the past 5 decades there have been considerable changes to the catchment, and to the lake itself. It is likely that the lake is no longer in a state of long term dynamic equilibrium as it would have been previously when it behaved as an ICOLL. Future catchment development will result in a continuing state of change in the lake dynamics.

There have been four categories of activity which summarise the changes that have influenced Currimundi in recent years.

- The political decision in the 1960s to legislate that the entrance be kept open. From the data available this decision has been interpreted more in that there should be always tidal flow between the lake and the ocean, rather than there being a full tidal exchange with the ocean. Subsequent development in the Kawana estates has assumed that the entrance will be kept open for flood minimisation.
- In 1980 the lake system was extended to include the Pangali and Baroona Canals and then in 1994 the Tokara Canal was completed. This was associated with the start of rapid increase in population with associated stormwater runoff and water quality issues.
- In the early 2000s the influence of the Lake Kawana development began to be felt with the temporary weir being installed which in effect connected Currimundi to Lake Kawana during spring tides. It is expected that by late 2006 the permanent weir will be finished. In addition to the increase in tidal flow via this weir there is also a constant flow discharge coming indirectly from the Mooloolah River to ensure adequate flushing of Lake Kawana.
- Finally, in 2003 a major dredging activity saw the removal of much of the sand plug at the entrance over a relatively short period of time. This was the first time dredging of this magnitude had been carried out.

All of these events will be acting to change the preferred state of dynamic equilibrium and hence their impact must be understood before management strategies are developed for the future.

It is also important to note that the region has been affected by climatic variability which has seen over 3 decades of relatively low storm activity and freshwater flooding. A geological study (Hekel and Day 1976) supports a view that the sediment supply to the Sunshine Coast beaches is controlled by the North Passage shoals, which will be susceptible to climate variability and in particular Inter Decadal Pacific Oscillations which can result in variability in the amount of sand available for beach building. It is possible that since 1980s there has been less sand on the beaches resulting in more cutback and hence thinner and lower berms. Under these circumstances Currimundi entrance in an open state will be exposed to more wave induced sediment transport into the entrance.

1.6.2 Issues of Concern

The community of Currimundi has been expressing concern over water quality and other issues at various times. Council has responded usually with either the commissioning of specific studies or the development of management plans. These studies, plans and other documentation have been examined to identify key information relevant to future management action.

As a lead up to this study, two internal stakeholder groups were convened to identify the range of issues affecting the lake and future management options. These workshops identified critical areas of community concern which will now be discussed. Where these issues have been addressed in the past, reference will be made to previous studies or discussions.

In many regards, the future management options for the lake have been tackled before, particularly in the WBM (2000) report. Also the Caloundra City Council Lake and Estuary Risk and Operational Management Protocol (LEROMP) document prepared by Council Officers provides both an excellent overview of the issues, but also a risk management framework for action. However, it is appropriate to test these plans, or possibly develop a new strategy, in light of the current circumstances.

The various reports, workshop findings and Council documentation raise many matters of concern or observation. For example, at a preliminary internal CCC stakeholder meeting in April 2006, the following were raised as representing current concerns.

- Bank erosion along the full length of the lake
- Front beach erosion
- Increase in tidal prism
- Silt build-up
- Midge problems since 1960s – ideal habitat since 2003
- Vegetation change
- Infrastructure below flood level
- Anecdotal view that ICOLL open about 90% of time since 1988
- Concern over storm water inputs and sewage overflows lake is going brown – tannin or coffee rock or construction sediment
- Algae – from offshore or from lake and die-off on opening
- There are major catchment wide problems – MMTC and CAMCOS transport corridor construction
- Problems with Acid Sulphate Soils (ASS) and pipe corrosion
- Concern over high Faecal Coliforms at times
- Need values analysis

- Water quality generally
- Flooding.

Similar issues have been raised previously and documented, and were again highlighted in the Think Tank meeting in August 2006. As a first attempt at providing an integrated overview, these concerns can be categorised into the following key issues:

- Biting Midge Nuisance
- Tidal Hydraulics and Entrance Dynamics
- Bank Erosion
- Lake Ecosystem Health
- Influence of Lake Kawana

A review of the anecdotal information, reports and studies on these issues has been undertaken, and a summary of the main points follows. Of note though, in most cases there has been a degree of isolation associated with the development of this information. However in most regards these issues are inter-related and an attempt will be made to integrate all of these issues into as simple a summary overview as possible in a following section.

a. Biting Midge Nuisance

Council Officer reports (Butterworth 2005) and the LEROMP document summary provided the most relevant data on midge. Anecdotal information from prior to 2003 suggests, quite reasonably, that midge has been an intermittent problem which was related to the entrance opening. Closure a few times a year disrupted the breeding cycle: midge would migrate upstream when open.

Figure 2: Sand Plug Removal 2004

Biting midge populations increased significantly following the 2004 sand plug removal (Figure 2), but midge populations are known to fluctuate over time. Given that there had been no previous dredging activity of this magnitude it is understandable that the midge increase was dramatic.

The cause is most likely that although a significant section of sand flat habitat was removed by the dredging, the increase in tidal range (not monitored) throughout the lake as a result of greater hydraulic exchange at the entrance would have increased the exposure of sand flats, and hence habitat, further upstream. Re-profiling of the northern banks would have also contributed.

b. Tidal Hydraulics and Entrance Dynamics

These issues have been examined in the report by Wilkes (1995) and by WBM (2000). Wilkes (1995) examined entrance management strategies following on from the 1993 Management Plan. These studies put forward a view that when the lake entrance is opened artificially, water quality is improved. However, this view is not supported by subsequent experience where fish kills have occurred following entrance opening. Equally anecdotal evidence suggests that during spring tides, the increased ocean water exchange has no impact on the fish population. A more holistic interpretation of lake ecosystem dynamics is required.

Other information provided in these reports include importantly, that the northern bank erosion was evident as early as 1958. Other observations where that the entrance was closed for a year in 1989 and that lots of trees fell due to elevated water level and resulting saturation of the embankments. Also it was noted that the entrance was artificially opened in 1994. Wilkes proposed a water quality monitoring program, but only collected limited data.

Wilkes (1995) and others have advocated a berm height management strategy that it would be best to keep the entrance semi-closed and that would break through during flood. This idea has been adopted by Cardno and Davies (1998) for flood studies which were based on the physical modelling by the University of New South Wales Water Research Laboratory in the 1970s which showed that the entrance would open early in the flood hydrograph. The problem is that if the berm is too low then it is likely that even moderate storms could breakthrough and create a natural opening more frequently than by flooding.

The WBM (2000) report developed a tidal dynamics model, but as it was uncalibrated and was only used for relative assessment of flushing options. This included the major work undertaken in recent times, namely the removal of the sand plug in 2004. There is no real new data in this report.

Historical photos and anecdotal information suggests that Currimundi was generally semi-closed with full closure on low tides (Caloundra City Council 2006). The lake was sometimes closed for months. Openings depended on fresh events. Aerial photos show a persistent sand plug.

The evidence of infilling since 2005 gives a good indication of the natural tendency for the entrance to be blocked by a sand plug and to have a small restricted meandering channel. Putting everything in context it would appear that the entrance has been basically unchanged between 1958 and 2001 despite the connection of the Pangali, Tokara and Baroona canals in the 1980s and 1990s.

Figure 3: Lake Currimundi 1958

There would have been an increase in tidal prism associated with these canals, but because the sand plug is dominated by beach processes, the tidal range will always be restricted provided the plug is present, and hence the increase in waterway area will be minor in influence on tidal prism. In tidal inlets of this type, there is a selfcorrecting process whereby an increase in tidal prism will lead to an increase in flood tidal flows and hence more sediment movement into the entrance. In the absence of major freshwater event to flush this out again, there will be little change. The impact of the 1974 flood is evident with a smaller berm. Other wet years such as 1992 show up with smaller berms as well. The much larger berm and extensive sand plug in 2003 may be due to the dry period at that time and perhaps more wave induced sediment transport across a weakened berm following the southern excursion of the entrance channel in 1999.

Aerial photos show that the entrance channel was predominantly taking a northerly path causing erosion of the northern banks in a similar fashion to that shown in Figure 4. This was regardless of the location of the exit point for the channel. The exception was in 1999 when it migrated to the south for reasons not particularly apparent but may have been as a result of the flooding in 1996 followed by flooding again in 1999. It is also possible that the increase in tidal prism due to the addition of the canals to the lake system was creating an influence. A strong possibility is that the processes associated with channel migration to the south will lower the berm across the front of the lake and consequently weaken it in terms of higher wave energy events. In this case significant movement of sediment into the lake would be expected. This may be the mechanism which resulted in the rapid growth of the sand plug leading up to the removal in 2004.

Similar flood induced breakthroughs and subsequent infilling episodes would have been likely following each of the major floods on record. SKM (2002) showed major floods occurred in June 1958, and that big events also were recorded in 1964, 1974 1989, 1992, 1996 and 1999.

It is clear from the recent surveys that more than half of what was removed in 2004/2005 has re-entered the lake. Caloundra City Council memos show that about 147,000m^3 was dredged between December 2003 and November 2004 and another 37,000m^3 up to 15 April 2005. About 72,000 m^3 has in-filled since then to 23 February 2006, with the strong likelihood of continued in-filling. This suggests that the there has been accelerated infilling most likely due to a combination of the tidal regime being forced out of equilibrium by the dredging; the increase in tidal exchange due to the connection of Lake Kawana at the temporary weir, and the accelerated shoreward sediment movement during the major storms in March 2006 and June 2006. The placement of some 88,000 m^3 of the sand plug into the Lake Kawana development is of some concern given that the sand originated from the active beach system, and its extraction from the active beach system may have had impacts on adjacent beaches.

Information from the Currimundi Catchment Care Group raises the issue of the extent of silt accumulation in the sand plug presumably as a result of upstream bank erosion, catchment land clearing and major earthworks. This may be significant and sediment bore sampling may be required to clarify the extent of silt on the Lake bed.

Aerial photographs show a rapid migration of the entrance channel from the northern bank to the south from November 2005 to July 2006, with a strong indication that the March 2006 storm was the main driving forces. This migration may have been triggered by the presence of dredge infrastructure which may have been blocking the northern channel to some extent. This resulted in erosion of infrastructure on the southern bank and subsequent action by Council to rebuild the berm and relocate the channel to the north. It should be noted that from the available aerial photos the channel predominantly has been to the north.

Figure 4: Entrance Conditions 2007

c. Bank Erosion

Community concerns have been raised about erosion of the lake foreshores (Figure 5). These have been raised at the internal stakeholder meetings this year and were the subject of a consultancy earlier this year (Witheridge 2006). The areas of concern referred to here are in addition to the erosion of the northern bank at the lake entrance which is considered to be related more to entrance dynamics.

Other sites (some of which have been referred to specifically in the documentation) have erosion problems which have been identified by Witheridge (2006) as being due to inappropriate vegetation, exposure of dispersive sub soil and redirection of flow at key locations. In general, from the anecdotal information, it appears that the main trigger for increased erosion is the increase in tidal range associated with an entrance opening. Certainly major concerns have been raised since the removal of the sand plug in 2004. Increased tidal range will result in saturation of the banks to a higher level and subsequent destabilization, allowing other factors such as boat wash, and flow re-direction to have a greater impact.

As a consequence of bank erosion and other factors such as sediment wash-off from major earthworks and catchment development, there are also concerns over the changing profiles of the canals and the Currimundi system itself.

Figure 5: Typical bank erosion

d. Ecosystem Health

Water quality data has been routinely collected by Council for some years, but at this stage the data have not been subject to any time series analysis to determine relationships between environmental factors, entrance regimes and other changes to the lake configuration and the occurrence of deterioration in water quality. The usual pulses following periods of rainfall and storm water runoff are evident however. Water quality issues are referred to in Wilkes (1995) and WBM (2000). Biological health was examined by Leggett (1997, 2000) who found a good variety of fish species and predicted that this should continue provided the mouth remained open. Earlier surveys in 1993 and again in 1997 suggested that there was a concern over bank erosion due to boating and poor water quality which subsequently improved due to the introduction of better management practices and community awareness-raising by Council.

Adopting the South East Queensland Ecosystem Health Monitoring Program (SEQ EHMP) methodology, Costanzo *et. al* (2002) identified 3 distinct zones based on a one-off survey over 5 days in April 2002. These results are not put into any seasonal or climatic context, but provide a good snapshot of the state of the Lake at the time of the sampling. They found that near the entrance the lake had low nutrients and chlorophyll a and higher DO. Water quality deteriorated through a transition zone with the opposite trends evident in the canals. There were also high sewage nitrogen levels and higher concentrations of nutrients, hydrocarbon and metals in the sediments. Another key finding was that the lake is primarily at ocean salinity and is stratified in the upper reaches. Again these findings would be highly dependent on climatic conditions. The University of the Sunshine Coast found Faecal Coliform levels above primary contact at 7 sites. High faecal counts during rainfall events are normal for urbanised areas.

It should be noted that future studies will adopt the Queensland Water Quality Guidelines 2006 to ensure relevancy to the Currimundi system. Specific Water Quality objectives have been produced for Caloundra City under the EPP (Water) 1997, Mooloolah River Environmental Values and Water Quality Objectives, March 2006. The Queensland Water Quality Objectives 2006 are also being adopted by the SEQ EHMP program.

The Currimundi Catchment Care Group and the Friends of Currimundi have been monitoring water quality for 3 years, and they report that there have been a number of occasions when water quality indicators suggests problems. Also of concern, are suspended sediment and nutrient levels recorded by the groups. Specific anecdotal information (e.g. Mark Lennard Pers comm) has noted recent changes in the Lake namely: increased turbidity and algal growth particularly in summer and after heavy rain.

Overall these results are typical of urbanised systems, but do suggest that the lake water quality was degraded at the time of the sampling.

The contextual information in the LEROMP document provides an excellent overview of water quality at this stage, noting that water quality and ecological studies have been limited and time specific.

The LEROMP summarises issues as follows.

- Some sites have elevated sediment nutrients
- There is stratification with low DO
- Previous studies identified need for extended monitoring.
- CCC has been monitoring regularly since 2001
- Potential impacts on lake ecology as a result of artificial entrance behaviour modification
- Mortality of aquatic plants and algae and impacts of riparian vegetation
- Changes in water quality cycles and processes as a result of artificial entrance behaviour modification
- Disturbance of nutrient rich sediments during excavations or dredging
- Potential eutrophication during periods of significant extended closure
- The impact of stormwater events is clearly indicated in previous data and CCC monitoring – need community education
- It appears that incidence of extreme odour or discolouration has not occurred before, but community may react if there is natural tannin staining and odour (rather than eutrophication) during semi-closure or closure of entrance and hence management is needed
- There is likely to be a “real” water quality problems in future with the opening of Lake Kawana
- Shark sightings after sand plug removal

The increase in shark sightings (an observation not supported by all anecdotal evidence) and increased turbidity are also of interest in that they provide support for the notion presented earlier that the removal of the sand plug increased tidal exchange and flow rates allowing for greater channel depths at the entrance and greater stirring up of fine bottom sediments further up the waterways.

At the Think Tank in August 2006 another area of potential concern raised is the rate of corrosion observed in Council infrastructure (pipe work) and the apparent link to Acid Sulphate Soils.

A common theme in a number of Council documents and at internal stakeholder meeting is the need for any management of the lake to be put into a whole-of-catchment perspective. In particular the development of the north-south MMTC and CAMCOS transport corridors, west of the Currimundi System and aligned through the Meridan Plains were seen as having an impact on catchment pollutant loads.

e. Influence of Lake Kawana

Considerable concern has been raised about the impact of the connection to Lake Kawana (Figure 6). This connection is via two elements (i) an overflow weir connecting to Pangali Canal and (ii) pumped discharge from Lake Kawana into Tokara Canal via an existing stormwater pipe system. The weir is required to limit the increase in the tidal prism of Lake Currimundi and to maintain a relatively constant lake level. Water is pumped from the Mooloolah River to maintain brackish conditions and to improve the flushing characteristics of Lake Kawana. Despite some inaccurate references in earlier correspondence, it has been established that the system parameters are as follows.

The weir height is constrained by the need to have a nominal lake level and to allow the egress of the 1.9 m^3/sec over a 12 hours pumping cycle (equivalent to 82 ML/day - could be as high as 137ML/day ultimately) that is pumped from the Mooloolah River as well as to allow the egress of stormwater which discharges to the lake from its 500 hectare catchment. The weir effectively prevents tidal exchange for tides lower than MHWS. Computations provided by the Kawana consultants suggest that with the ultimate weir configuration there will be a minor increase in tidal prism (around 10%) and velocities for tides higher than MHWS. This does not mesh with the anecdotal observations of tidal exchange at the temporary weir, however, and requires confirmation. The Cardno & Davies Impact Assessment (1998) indicates that Council have committed to keep the entrance open and the flood modelling done for Kawana Lake has been based on this. The design assumes that even if the entrance is closed, it will rapidly erode.

Analysis of CCC water quality data with respect to pH does not indicate any problems in the canal system or downstream of the weir. There is one outlying low reading at one site in the southern arm of Currimundi Creek (Erang St). The data show events, but no significant long term trends or changes at the critical times of development.

There is also the issue of the proposed 300 litre/second (13 ML/day over a 12 hour cycle) of lake water discharged to the top end of Tokara Canal via an existing stormwater pipe. This discharge would form part of the overall Lake Kawana circulation system, but may increase the incidences of discolouration of the canals. Anecdotal reports of discolouration of water in the canal to date are consistent with fines and colour being discharged from the new developments. Whether this represents a real deterioration in water quality is still unclear.

Figure 6: Lake kawana Weir 2007

1.6.3 Summary

Despite there not being any definitive examination of the state of Lake Currimundi, the Council documentation, previous studies and anecdotal information does provide sufficient background for the development of a broad conceptual understanding of the dynamics of Lake Currimundi. From a management point of view the lake system may be able to be considered in terms of characteristic units (for example the entrance, the southern and western arms, and the canals) where specific issues are more dominant, but it is important to consider that in terms of the dynamics of the system, it must be treated in a whole-of-catchment fashion, in order that management actions at one location do not impact elsewhere in the system.

Before presenting such a conceptual model, a couple of issues need to be noted.

Firstly, much of the community concern over the years relates to specific events and the impact these events have had on the lake. For example, the recent concerns over midge increases, bank erosion and entrance instability would seem to have been a direct response to the removal of the sand plug in 2004. The co-incidence of this event and its resultant impacts has unfortunately coincided with the connection of Lake Kawana to Lake Currimundi via the temporary weir. In these circumstances it is difficult to clearly define a cause and effect, particularly when the removal of the sand plug was by all accounts seen as a “positive” action by the community, and the Lake Kawana development seen as a “negative”. Consequently, negative impacts of the former may not be regarded that way.

Secondly, throughout the period of available studies and data since the 1980s there have been general climatic conditions of reduced sediment supply to beaches, elevated sea level, minimal major storm and flooding activity, and a rapid growth in coastal development. Consequently it is unlikely that the behaviour of the system during this period reflects a long-term equilibrium condition. The increased focus on monitoring bio-chemical parameters for environmental management has deflected attention from the need to understand the physical processes – particularly in coastal settings.

In general the system has changed as major changes were introduced over time:

Prior to 1980s the lake behaved as an ICOLL which was closed naturally during winter months and periods of low rainfall. It was artificially opened as per legislation in 1960s. These openings would not have been of sufficient impact to modify the lake ecosystem, other than to provide a short-term flush of stagnant water. Water quality no doubt fluctuated as well, but would not have been of concern generally. There would have been minor issues with bank erosion, again associated with opening of the entrance or extended periods of elevated water level beforehand, and the northern bank near the entrance would have been eroded back to the coffee rock due to the predominant wind and wave conditions at the entrance.

During the period from 1980 to the late 1990s the Pangali, Tokara and Baroona Canals were constructed. There would have been higher tidal flows during artificial openings. The entrance conditions generally remained unchanged with the entrance channel taking a northerly path to the sea. The midge problem was not significant due to the stability in the water levels. Water quality problems would have increased primarily due to the increase in urbanisation in the catchment with the development of the canals resulting in concentration of runoff and increase in pollutant loads. This general deterioration was accompanied by increased localised bank erosion as result of the construction of bridge and other waterway infrastructure deflecting flows from natural channel alignments.

Since the late 1990s there have major changes due to the connection of Lake Kawana, and the removal of the sand plug. The build-up of the sand plug in the years preceding 2004 was probably due to the combination of general reduction in regional sand supply causing a gradual recession of the beach, elevated sea levels, and the sequence of big fresh events in 1996 and associated apparent weakening of the sand berm. This allowed rapid ingress of sand into the lake under flood tidal flows and wave transport.

The removal of the plug would have temporarily increased tidal ranges, midge habitat, tidal exchange, bank instability as recently reported. The current rapid infilling is returning the lake tidal dynamics to pre-removal conditions with a low-flow tidal entrance channel meandering across the sand plug. The removal of the plug also saw a reduction in the ebb-tidal delta resulting in a narrowing of the beach immediately to the south, with consequent concerns from beachfront residents. This was exacerbated following the March 2006 storms when the entrance started migrating to the south further minimising the sheltering effect of the ebb delta. This also suggests for asset protection on the southern side of the entrance bank that a feasibility and cost-benefit analysis should be undertaken in terms of comparing erosion mitigation measures such as repeated and reactive entrance berm augmentation as opposed to harder one-off capital engineering solutions such as the construction of a buried rock wall thus allowing for the channel to migrate north and south through the entrance and minimising the impact of an erosion event on the southern bank.

Whether there is an overall return to earlier behaviour will depend on the impact of the additional tidal and non-tidal flows resulting from the connection to Lake Kawana. At this stage there is insufficient data on this and indeed insufficient time to see any longer term impact. Possible impacts which would cause long term shifts in the "dynamic equilibrium" include increase in the tidal prism, tidal range, freshwater runoff, all of which could modify the entrance behaviour.

There is a generally supported view that the entrance should be allowed to open and close as naturally as possible within the constraints of the legislative requirement for the entrance to be "open". There is also a view that the berm should be kept low allowing elevated flood waters to easily breakthrough. However, there is a counter view that suggests that if the berm is low then under conditions of elevated sea level and weakened beach widths, then there will be more wave and flood tide induced sediment transport into the entrance negating the benefits of the lower berm. There is also a view that the water quality improvement objectives of opening the entrance to encourage full flushing – if undertaken excessively - may have the negative effect of turning over the ecosystem causing a shock to benthic organisms and die-off, and a consequent rapid reduction in DO leading to fish kills.

CHAPTER 2 – COMMUNITY ENGAGEMENT

2.1 INTRODUCTION

Waterways are an important natural resource, which need to be preserved and maintained. They provide us with a source of water for a range of activities including drinking, recreation and agriculture. Waterways are environmentally, socially and economically essential to any community. Increasing development often results in adverse effects on our waterways and there emerges a need to preserve and maintain their health and sustainability. The standard to which our waterways are maintained and preserved is highly dependant on the predominant land uses in a particular area and the value the community places on their ability to pursue these uses. Any future management systems for the Lake Currimundi catchment will be required to find some balance between past, existing and future land use planning schemes and management systems and their related values and objectives.

2.2 ENVIRONMENTAL VALUES

The importance or worth placed on a waterway by the community is identified through Environmental Values (EVs). EVs are an indication of the many possible environmental qualities, characteristics or uses that could be recognised in a waterway or aquatic ecosystem. Selecting or determining EVs for a waterway is fundamental to determining the direction of management strategies for that waterway, and developing knowledge to assess and monitor the performance of those strategies.

The National Water Quality Management Strategy (NWQMS) recognises a broad set of environmental values that can be identified for a particular water body.

The Queensland Environmental Protection Agency (EPA – now the Department of Environment and Natural Resources) has identified 13 EVs to be considered for waterways and catchments in south-east Queensland. These EVs are identified in the Environmental Protection (Water) Policy (EPP), which was based on the National Water Quality Guidelines (ANZECC, 1992). These EVs are listed and described in Volume 2 - Appendix 4.

The formulation of EVs is essential to the successful management and sustainability of Lake Currimundi and its sub catchments. The process followed for this study was an initiative of Caloundra City Council’s Waterways Unit and the Griffith Centre for Coastal Management (GCCM). This process is reasonably new to south-east Queensland and is continually being developed by the EPA in conjunction with local governments and catchment management organisations.

The development of EVs for catchment systems relies on consultation with the community and stakeholders and is supported by scientific research and data collection on the health and status of the catchment ecosystems.

2.3 COMMUNITY CONSULTATION

2.3.1 Workshop of Experts

An expert panel workshop (Volume 2 - Appendix 4) was held on October 18, 2007, to discuss:

- The key management options available to Council, namely entrance management, pollutant source control
- Identify points of agreement and disagreement in relation to major issues and their relationship with management options and other issues such as biting midge, tidal hydraulics and entrance dynamics, bank erosion, lake ecosystem health, and the influence of Lake Kawana

Some of the main points to come from the workshop included:

Midge

- Numbers building due to increase in available habitat
- Closure of entrance needed to reduce/kill midge population
- Different management techniques considered
- 2004 closure successful

Sand Plug/Dredging

- Need to manage entrance to the north with sand movement
- Berm and channel created with natural longshore drift process
- Channel migrates south due to wave direction and longshore drift
- Plug provides major frictional resistance to tide. The removal contribute to tidal range

Bank erosion

- Bank erosion was occurring prior to lake becoming an estuary
- Erosion caused from recreational impacts
- Bank saturation occurs when the entrance is closed

Lake Kawana weir

- Need to monitor flow rates from the weir
- The increased flow into Currimundi is most likely beneficial
- There is little benefit in modifying the weir.

Water quality

- Water quality is and remains stable
- Nutrient levels have been dropping
- Water is healthy and fish population is good
- Need for three permanent monitoring systems

Past issues and management strategies for the lake were also discussed.

2.3.2 Information Sheet and Community Survey

Initial consultation with the community in the Currimundi catchment was undertaken via an information sheet and invitation to a community meeting to complete a community survey. A copy of both the information sheet and community survey is included in Volume 2 - Appendix 4.

The information sheet was intended to provide background information on the study, its expected outcomes and the study area, as well as information on opportunities for community involvement and contact information.

The information and feedback received via the community survey provided valuable information on the community's understanding of the health of the creek, their expectations and issues, and opinions on what they saw as possible environmental values for the lake system. The results of the survey are included in Volume 2 - Appendix 4 along with a summary of all feedback provided throughout the course of the study.

A summary of the results of the survey is as follows:

Of the 52 respondents, the majority of the responses to the questions indicated that respondents:

- Were male (55%, with 37% female)
- Were aged 51-70 years (65%)
- Owned a property on Lake Currimundi/Creek/Canal (73%)
- Resided in the area for 4-6 years (30%) and 7-15 years (24%)
- Used the lake system on a daily basis (61%)
- Are part of a community group (62%) – Both Friends of Lake Currimundi (35%) and the Lake Currimundi Catchment Care Group (26%)
- Use the lake for walking (32%), kayaking/canoeing (15%) and fishing (12%)
- Thought the opening/closing or moving the entrance was not an effective management option (44%), yet 38% disagreed
- Accessed their information on the lake from other sources (35%) such as community newsletters as well as Caloundra City Council (27%)
- Thought that the current state of the lake was Fair (49%)
- Ranked water quality as the top priority issue (23%) followed by bank erosion (15%) and midge (14%)
- Ranked Bank erosion as the second priority issue (21%) followed by water quality (20%) and boating and recreational issues (15%)

2.3.3 Stakeholder Identification

GCCM and Caloundra City Council (CCC) have placed a major emphasis on bridging the gap between management decision-makers and the community. The Lake Currimundi Dynamics Study was aimed at developing an adaptive framework for the identification of stakeholder requirements and maximum community involvement. The approach has been to engage key stakeholders and the community in the preliminary phase of the project in order to appropriately develop and assess values and issues for the Lake Currimundi catchment. This approach is somewhat new in its application and aims at setting higher standards for similar projects undertaken in the future. It also aims at further increasing the relationship and interaction between decision makers and the broader community.

Stakeholders were identified and classified as follows:

Government Stakeholders

- Sunshine Coast Regional Council (formally known as Caloundra City Council)
- Stocklands

Non-Government Stakeholders

- Lake front land owners and residents
- Non-lake front land owners and residents
- All Caloundra land owners, residents and visitors
- Businesses in the area
- Clubs, associations and community groups
- Local business operators
- Ratepayers
- Educational institutions
- Indigenous groups
- Tourists
- Local environment groups and organisations

Identification of stakeholders and their requirements is critical in aiding to obtain appropriate management solutions. This investigation has focused heavily on establishing these requirements and views as early as possible. To aid in achieving this, a preliminary stakeholder/community meeting was held.

2.3.5 Community Presentation

A presentation to the community of the preliminary findings and outcomes of the research to date was held on December 6, 2007 at The Events Centre, Caloundra. The attendees consisted of local residents, local industry, community groups, local government officers and councillors. The presentation was aimed at informing the community of the progress of the dynamics study and presented the community with the preliminary results of the research being undertaken. The presentation covered 3 main areas:

- Recent history of Lake Currimundi
- Current issues of concern including water quality
- Adaptive Management Framework (AMF)

The attendees at the meeting were asked to complete a community survey and to raise issues for discussion with researchers and project coordinators. Following lengthy discussions and an overview of issues and concerns from residents and other stakeholders, attendees were given the opportunity to become further involved by becoming part of a stakeholder working group. Those interested were asked to provide contact details and from this a Lake Currimundi Dynamics Study Stakeholder Working Group was formulated.

2.3.6 Stakeholder Working Group

The purpose of the stakeholder working group was primarily to establish a set of EVs for Lake Currimundi catchment. Selecting or determining EVs is fundamental to determining appropriate water quality objectives, direction of management strategies for that waterway and developing knowledge to assess and monitor performance of those strategies.

All stakeholders were invited or given an opportunity to become involved in the working group. The members of the working group consisted of those who were interested from the community meeting and from a list of invitees, aimed at providing a broad cross-section of stakeholders. Details of those stakeholders invited to become involved are in Volume 2 - Appendix 4.

It was proposed to have two working group meetings to formulate EVs. The first meeting was aimed at providing background information on the research being undertaken and how this may contribute to EVs formulation. The processes of EVs were covered in some detail, giving examples and working from issues raised by the stakeholders. The second workshop aimed at formulating and finalising EVs as well as focussing on issues not covered by the EV process such as biting midge and bank erosion. Agendas and summaries of these working group meetings are included in Volume 2 - Appendix 4.

The meetings were held at Lake Kawana Community Centre and were facilitated by coordinators from GCCM, CCC and the University of the Sunshine Coast.

2.3.7 Formulated Environmental Values, Issues and Concerns for Lake Currimundi Catchment

The proceedings and a summary of the first stakeholder working group meeting held on February 12, 2008 are included in Volume 2 - Appendix 4. The group was asked to identify what they thought were appropriate EVs based on a list of possible EVs used by the EPA (note: other values were added where deemed necessary). By focussing on issues of concern within the catchment, the group was able to identify EVs associated with addressing these issues. These values were identified individually by members of the group. Individuals were also asked to prioritise these identified values in terms of high, medium and low priority. High being those values seen as most important to protect or conserve, or needing short term attention and/or actions.

The final EVs were formulated primarily with respect to the information gained from the stakeholder working group, however information and input gained from the community survey, researchers and other feedback from stakeholders was also incorporated into the values formulation. Information used to formulate final EVs is included in Volume 2 - Appendix 4.

The proceedings and a summary of the second meeting held on March 12, 2008 are also included in Volume 2 - Appendix 4. This second meeting was aimed at finalising the identified EVs and identifying and discussing the issues of concern not associated with those values and with Lake Currimundi in general.

It became apparent that many of these issues were directed at water quality and not a broader range of community issues. Some community values were also identified, expanding of the EV process. Definitions and explanations of EVs are included in Volume 2 - Appendix 4.

2.4 SUMMARY OF ENVIRONMENTAL VALUES, GOALS, ISSUES OF CONCERN

The following gives a brief summary of the most highly prioritised environmental and community values that were set for Lake Currimundi catchment, including the main issues of concern to the community and stakeholders:

- Aquatic ecosystems, wildlife habitat, human consumers, primary and secondary recreation and visual recreation were the most highly prioritised EVs in need of conservation and protection
- Installation of effective stormwater pollutant traps
- It was identified that the appearance and turbidity of the water was a major concern to those who use the lake for recreational purposes
- A noticeable reduction in bird life has been noted in the lake since the increase of dredging by Council
- Lake Kawana was noted as a possible contributor to the poor water quality and deterioration of the lake

The main concerns of the community were based on rapidly increasing development in the catchment and the negative impacts on the catchment and in-stream health. Appropriate management strategies and actions were sort after to allow for a more sustainable catchment system.

The formulation of Environmental Values for waterways and catchments is becoming increasingly important in today's environmental management practices. With increasing development and adverse human impacts on our waterways, there is an increasing focus on the need to preserve and maintain their health and sustainability. Much effort and resources have been devoted to investigating and developing sustainable programs, guides and management practices aimed at the long term sustainability and preservation of our waterways and catchments. The method adopted for Lake Currimundi was devised in a process coordinated by GCCM and Council.

This study indicates the importance of water quality and bank erosion as environmental values of highest priority to the community. Management strategies and/or actions recommended to address these top priority issues are included in Chapters 3 to 6. These recommendations form a part of more a whole catchment adaptive management plan aimed at providing the pathway to a healthy, diverse and sustainable catchment system.

CHAPTER 3 – BITING MIDGE

3.1 INTRODUCTION

The original tasks proposed for this study did not specifically address the characteristics of the biting midge problem, nor the management options already implemented or proposed (See Appendix 3). However, biting midge was identified as a major community concern (Chapter 2) and SCRC Officer – Vern Butterworth – had been undertaking significant studies of the problem over the years, and his findings have been incorporated here. Throughout this chapter conceptual frameworks will be presented for the relationship between midge population, the state of the lake in terms of water level and bank characteristics, and the nature of entrance opening/closing cycles.

3.1.1 Background

Prior to the early 2000's Lake Currimundi and surrounds were thought to be free of the common estuarine insect menace, the biting midge. However since that time the Lake Currimundi system has occasionally supported large populations of biting midge when conditions that suit its lifecycle have prevailed. At times these biting midge have had a significant adverse impact on the lifestyle of residents and the recreational enjoyment of the lake and surrounds by visitors.

Research and study of the midge by Council is on-going and it is starting to define the lifecycle parameters of the midge and to identify successful control strategies.

3.2 BITING MIDGE

In coastal Australia the impact that estuarine biting midge can have on adjoining residential areas has been well documented. Biting midge are a tiny species of fly (see Figure 7) that can cause extreme distress due to their feeding habitats on a scale that far exceeds their small size. The female biting midge requires a source of protein to mature her eggs. Human blood is a suitable source for this protein and her attacks on humans, often in large swarms, and the ensuring reaction to her bites cause responses ranging from mild annoyance to allergic reactions requiring hospitalisation.

Figure 7: Adult Biting Midge

Estuarine biting midge undergoes complete metamorphosis during their lifecycle (see Figure 8). The female lays her microscopic white eggs on damp sand in the intertidal beach zone. After about a week these eggs hatch into a white worm like larvae that burrow into the sand to live and feed. Here it undergoes four stages of growth (instars), each getting successively larger until it reaches about 5mm in length. This larval stage generally takes about five weeks and when complete it migrates to the surface of the sand and pupates. This air breathing stage is largely immobile and it is where the development of the winged adult takes place. After about four days the pupal case hardens and cracks open, the adult midge emerges, allows its wings to dry and then flies off to join other swarming adult midges or to harbour in shady vegetation nearby. The lifecycle is shorter during the warmer summer months and during cold winters the midge larvae can slow or even suspend development for some months. The hatching of adults is closely aligned to the lunar cycle and large numbers of adults can appear to arrive within the space of a couple of days.

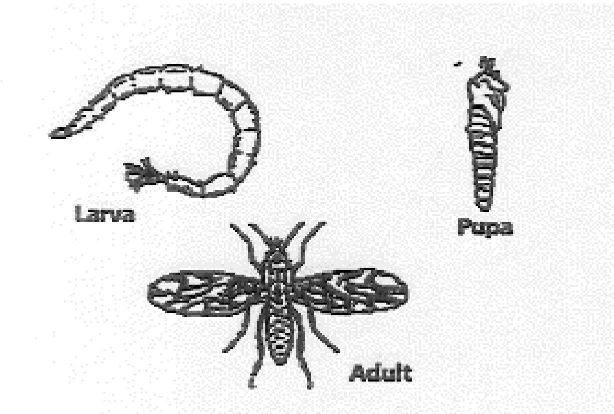


Figure 8: Stages of the Biting Midge Lifecycle

3.3 BITING MIDGE IN LAKE CURRIMUNDI

Lake Currimundi is an Intermittently Open and Closed Lake and Lagoon (ICOLL) and until recently its natural cycle of periodically opening then slowly closing off to the ocean over several months before reopening again due to rainfall or adverse weather occurred without significant interruption. Prior to the early 2000's adverse biting midge impact at Currimundi had not been recorded by Council.

3.3.1 Recent Increase in Biting Midge Abundance.

Anecdotal evidence from the early 1990's suggests that biting midge populations at Lake Currimundi very rarely reached populations large enough to have an adverse impact on humans and that impact was neither sustained nor significant. However in the spring of 2003 adult populations of biting midge were observed in the area and in April 2004 the first complaints from residents of midge attack were recorded by Council. The number of complaints grew steadily during 2004 to the point that petitions containing around 300 signatures were presented to Council calling for urgent action to address the problem.

It is not known with certainty why the biting midge populations seemed to suddenly explode in this locality. It is likely that a combination of circumstances favoured the biting midge and their impact was widely felt for the first time. Those factors probably include:

- the failure of the ICOLL to close naturally as it had done regularly in the past. It had been open to the ocean for almost three years by the time the first complaints were received,
- a large sand plug had grown and migrated upstream from the mouth of the lake. Over a number of years it evolved into ideal midge breeding habitat with a large flat stable expanse of beach at the ideal elevation with high levels of organic matter for food for larval midge,
- almost a decade of low rainfall and few floods during that time may have benefited the midge by limiting scour on sandbank larval habitats and allowed the increased build up of organic food reserves,
- the connection of canals to upstream sections of the lake during the 1980's and 1990's had increased the tidal prism and possibly increased the vertical tidal range (i.e. lower low tides). This could have increased the sandbank habitat available to the midge,
- increasing urban development within the catchment that resulted in gradually declining water quality, increased siltation and sedimentation may also have contributed to the increase in biting midge populations.

3.3.2 Identification of the Biting Midge.

Council commenced investigation into the biting midge problem in autumn 2004. The midge was identified as an undescribed species that has not been recorded elsewhere. It is now known as ***Culicoides sp. nr. subimmaculatus (Currimundi form)***. As its name suggests it is a close relative of the common estuarine midge ***Culicoides subimmaculatus*** and it is thought to share many of the lifecycle and habitat traits of that species.

The behaviour of this species is fairly typical of most estuarine biting midge species in that:

- its lifecycle is closely linked to the lunar cycle with adults hatching around the quarter moons,
- it has distinct peaks of adult activity in spring and late summer into autumn,
- the adult females feed on warm blooded animals to obtain a source of protein (blood). That protein is used to mature batches of eggs (around 60 per batch). Males do not feed on humans,
- adults are crepuscular feeders with most activity at dawn and dusk but they will also feed all day when overcast calm conditions occur,
- adults rest and shelter in areas of shady vegetation alongside the beach larval habitat,
- its larvae have been collected from intertidal beach habitats ranging from clean sand through to solid mud with a preferred habitat roughly halfway between these two extremes,
- larval densities as high as several thousand larvae per square metre have been recorded,
- larval densities over about 200 larvae per square metre indicate that after the next hatch adult populations will have a significant impact on adjoining urban areas,

- its preferred larval habitat is much higher in the tidal plane than other estuarine midge. Highest densities are recorded around Mean High Water Springs.

3.3.3 The Affected Areas.

At their greatest extent midge larvae have been recorded from all sandy and sand/mud beaches in the Lake Currimundi system. This is generally restricted to those areas downstream of the Ahern Bridge. However upstream of the bridge on the southern and western banks some small beach areas exist that have at times provided larval habitat.

The residential areas that immediately adjoin these larval habitats are naturally the areas most heavily affected by adult biting midge. The first line of dwellings suffer the heaviest attack but at their peak abundance complaints have been received up to 400m from the lake foreshore.

Downstream of the bridge the southern beaches record higher larval densities than the northern beaches. This is probably due to the generally flatter nature of those southern beaches and there being less exposed coffee rock in the intertidal zone.
Midge larvae have not been recorded from the active beach areas of the sand plug just inside the mouth of the lake. Those areas of clean beach sand are low in organic matter so they are lacking in food, are regularly subjected to wave action and do not provide a stable environment due to their almost continual movement. The southern section of the sand plug did at one time provide ideal larval habitat and those circumstances are discussed elsewhere in this report.

3.3.4 The ICOLL Cycle and Midge Abundance.

It is thought that the natural ICOLL cycle of Lake Currimundi maintained midge populations at relatively low levels in the past. When the ICOLL is closed the midge use a narrow strip of damp sand/mud beach just above the waterline to maintain their breeding cycles. From such a small area the midge could never build up populations large enough to have a significant impact.

When the lake opened and turned into a creek with a limited tidal range it rarely stayed that way long enough for the very small midge populations to exploit it to any great extent. The increased breeding habitat (i.e. the now much wider beaches) that resulted from having a limited tidal range and lower overall water levels would have probably resulted in a short term rise in midge abundance. However within a short time, usually within twelve months, the ICOLL would close, the water level would slowly rise due to rain and runoff, and a near constant water level would re-establish. The midge would go back to having a very limited breeding habitat at their disposal and adult populations would never reach significant levels of abundance.

It is highly unlikely that this midge species has recently moved into the Lake Currimundi environment, it is far more likely that it has actually evolved in this system and other ICOLLS like it. This is supported by the fact that this species has not been recorded elsewhere and that it displays some behaviours that would enhance its survival at times when the lake was closed. These behaviours include having peak larval abundance around mean high water springs and the ability to vary its egg laying habitat in response to varying water levels.

The gradual change in the dynamics of Lake Currimundi over the last few decades is believed to be the primary reason that this midge can now attain population densities that are high enough to affect adjoining residential areas. It has been observed that the midge populations can build up quickly when the system remains open and it has been the disruption to the natural cycle of this ICOLL that has been of greatest benefit to the midge.

3.4 REDUCING BITING MIDGE ABUNDANCE

Since 2005 several strategies aimed at reducing the abundance of biting midge have been implemented by Council with varying degrees of success.

3.4.1 The Flood Mitigation Dredging.

In early 2004 work began to remove the large sand plug (see Figure 9) that had accumulated inside the mouth of the lake to reduce the risk of upstream flooding. Around the same time larval biting midge sampling had identified that the southern half of the sand plug was ideal larval habitat with densities over 1000 larvae per square metre often recorded. That section of the sand plug had been stable for many years and contained high levels of organic matter. Complaints of adult activity were regularly recorded from the area.

Figure 9: Lake Mouth & Sand Plug 2003

To address the midge problem the dredging plan was amended to include more of this larval habitat so that it was removed and a much narrower, steeper beach on the southern bank was established (see Figure 10). About 20,000 square metres of larval midge habitat was removed and only about 1000 square metres of possible habitat remained along the southern beach.

Figure 10: Reduced Midge Breeding Habitat 2005

As a result adult biting midge almost vanished from the ocean end of the lake for several years and now only low levels of larval activity are recorded along the southern beach.

3.4.2 Barrier Spraying.

The application of long lasting residual insecticides to resting and harbourage areas had been shown to be an effective form of adult biting insect control in Hervey Bay. In late 2005 and early 2006 spraying trials were undertaken in Gamban Esplanade, an area where adult biting midge impact was at its highest along the Lake Currimundi foreshore.

The breeding habitat was separated from the residential area by a 20 metre wide strip of mown grass and a road. Only the occasional shrubs and small trees were scattered within the grass strip. Bistar was applied to the grass strip and the trees and shrubs at recommended rates on three separate occasions when adult midge populations were high. Results were inconsistent with some residents reporting relief from midge for as short as two days while other residents reported up to a month. It appeared that the midge were not stopping or resting to any significant degree in the treated strip.

The absence of a barrier to attract or force midge to land was identified as the primary reason for the lack of effectiveness of the treatments. The environment within the public land did not facilitate barrier treatments and as a result they were unsuccessful. Barrier spraying of the public land was abandoned and residents were advised to consider having barrier treatments undertaken within their own properties as this form of treatment was far more successful in Hervey Bay.

3.4.3 Lake Closures

The flood mitigation dredging had no impact on biting midge populations further upstream and their populations continued to slowly increase. Public pressure also continued to increase and in early 2005 Council resolved to close the lake for up to a month to determine what impact that may have on midge populations. It was thought that by replicating the former natural ICOLL cycle the biting midge populations would be reduced.

Monitoring had shown that the midge hatched on the quarter moons so the closure was timed to cover at least three quarter moons over the lunar cycle. It was thought that flooding the larval habitat when a significant hatch of adults was imminent should result in juvenile midge drowning when they pupated, there was the possible increased predation on midge larvae by fish and other aquatic organisms and it was hoped that the disruption to their lifecycle would result in lower adult populations.

The lake was closed in mid February 2005 and larval midge populations were monitored at several sites on a weekly basis. When that monitoring showed that larval populations had collapsed the lake was re-opened in mid March 2005. Midge monitoring was continued to determine if there was any ongoing impact. Figure 11 details the results:

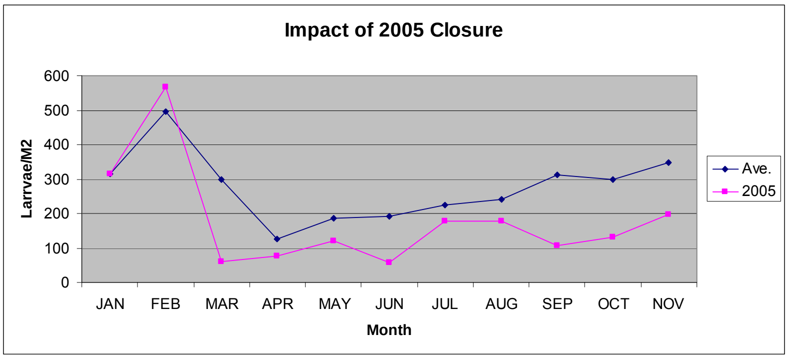


Figure 11: Lake Closure February 2005

The larval sampling indicated that larval densities were reduced by an average of 49% over the next nine months. More importantly adult populations collapsed totally during March and stayed that way in the following month, a period when adult populations were usually at their highest.

Biting midge recolonised the foreshores after the closure at varying rates. By the autumn of 2007 larval abundance was back near average and adult midge impact was also on the increase. Larval sampling in winter of 2007 showed abundance was increasing to well above average levels and a large hatch of adults was likely in spring.

Based on the success of the closure during 2005, Council provided ongoing funding for the annual closure of Lake Currimundi. It was decided to trial a closure to coincide with the spring adult hatch as a closure early in the season might have an increased impact on populations later in the season.

The lake was closed in mid September 2007 and was re-opened at the end of October 2007. The impact on midge abundance was far more significant than the previous closure as detailed in Figure 12:

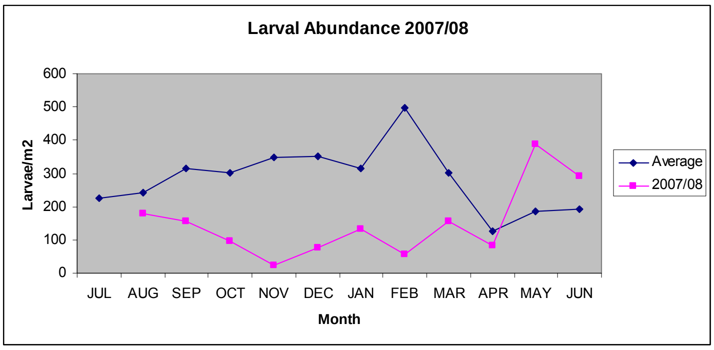


Figure 12: Lake Closure September 2007

The closure of the lake in spring of 2007 resulted in larval midge abundance being 67% below average over the following six (6) months. This resulted in very low adult populations and only a couple of locations experienced short term sporadic nuisance populations of adult midge.

The weather during the summer of 2007 was also not favourable for biting midge. Above average rainfall, large seas and almost continual strong onshore winds resulted in average water levels in the system being much higher than usual. The onshore winds caused regular filling of the mouth of the lake with sand and on three separate occasions the lake partially or fully closed for periods of up to two weeks. These higher water levels resulted in narrower beach areas being available as midge breeding habitat and probably enhanced the impact of the closure of the lake during the previous spring.

Larval populations returned to above average levels by the winter of 2008 so the lake was closed in late August 2008 to coincide with the new moon high tides. During the previous closure in 2007 it took two weeks to raise the water level to completely cover the larval midge habitat. Due to some timely rain the midge habitat was completely submerged within a week. Also a higher water level was set to try and limit the opportunity for adult midge to lay their eggs in the damp sand just above the static water level, a phenomenon observed during the 2007 closure. Figure 13 shows the results to date:

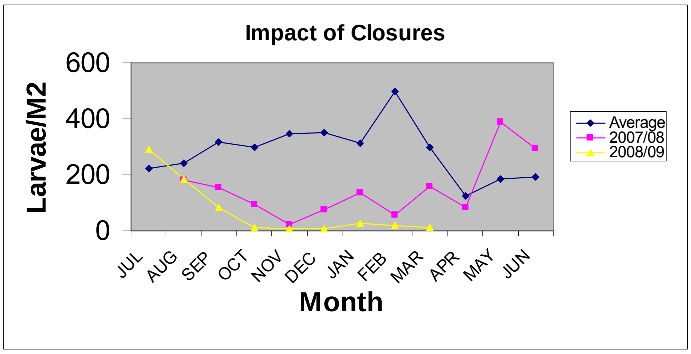


Figure 13: Lake Closure August 2008

The improved results have continued with larval abundance being 96% lower than average in the six months since re-opening the lake.

We can only speculate as to why the results are so much better in 2008/09 but the higher water levels and the longer period that the breeding habitat was submerged are probably the key factors. The cumulative affect of consecutive annual closures may also be a factor.

Only one report of adult midge activity was recorded during 2008/09 which highlights the significant impact on biting midge populations of the most recent closure.

3.4.4 Beach Modifications.

In 2005 works were undertaken to stabilise undercut banks along the northern side of Lake Currimundi at Crummunda Park. An excavator was used to scrape sand from the beach and repack it against the undercut banks. This resulted in a much steeper, more stable beach. The biting midge larval habitat was disturbed to such an extent that larval densities collapsed immediately. The steeper beach also resulted in a narrowing of the habitat as less surface area was exposed to the limited tidal action. Since that time midge larval densities have been very low to non-existent when prior to those works several hundred larvae per square metre were regularly recorded.

3.4.5 Proposed Larval Habitat Modifications.

At one site in the lake the midge abundance is always much higher than surrounding areas and nearby residents are more regularly affected by adult midge. It is known as the Gamban Esplanade Basin (see Figure 14).

Figure 14: The Basin, prime larval midge habitat.

It is a sandy mud area of around 1200m^2 with a higher bank of marine couch along one side that buffers it from the wave action of the main body of the lake. When the lake is re-opened midge recolonise this area much faster than other areas of the lake and larval densities are usually much higher here as well. The close proximity of residences makes this site the key problem area within the lake.

Minor habitat modifications have been proposed in this area with an aim of reducing its midge productivity and an application is currently under assessment by the Queensland Department of Primary Industries and Fisheries (QDPI&F). As part of that application process a study was undertaken to determine the elevation or height on the beach where the larval midge abundance was greatest.

Intensive larval sampling of the basin and surrounds to accurately determine the larval habitat and the areas of peak larval abundance was undertaken over several months in mid 2008. At the same time Councils Coastal Engineer also undertook a topographic survey over the same area at 50mm elevation intervals. The Australian

Height Datum (AHD) levels from that survey have been referenced to tidal elevations in the table below:

Tidal Plane	Caloundra Headland	Level from Survey (AHD)
Highest Astronomical Tide	2.04m	1.05m
Mean High Water Springs	1.62m	0.63m
Mean High Water Neaps	1.32m	0.33m
Mean Sea Level	0.95m	-0.04m

We combined the data from the larval sampling and the topographic survey and found that larval midge were recorded from below MHWN (0.33m AHD) to well above MHWS (0.63m AHD) with a peak abundance from just below to about 10cm above MHWS (0.6 to 0.7m AHD). Figure 15 highlights the larval midge distribution:

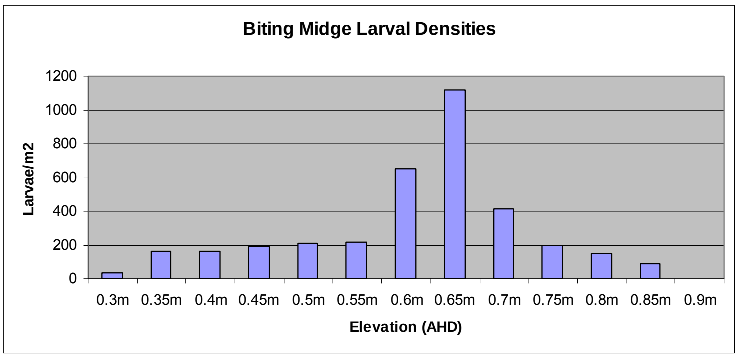


Figure 15: Identification of Peak Larval Abundance.

The relatively high elevations of peak larval midge abundance may be in response to the unpredictable water levels typically associated with ICOLLs. A preference for larval habitat high in the water level range would increase the chance of survival of midge larvae and pupae when the lake periodically closed naturally and water levels became static.

It should be noted here that Lake Currimundi is an ICOLL and it does not display the typical tidal range of a fully tidal estuary (i.e. a range of about 2m in this locality). The width and depth of the mouth varies and this variation along with the perched nature of the lake limits the vertical range of the water level in the system. Discharges from Lake Kawana and rainfall can also influence the water levels.

Water levels rarely fall as low as Mean Sea Level (MSL). At low tide the actual water level is often just below the MHWN level of the nearby ocean. Only tides above MHWN appear to have a significant effect in raising water levels in the lake and the difference between daily high and low water levels only averages about 0.3m.

The proposed habitat modification of the basin is to lower the beach elevation by about 200-300mm so that it no longer lies within the peak larval midge abundance range between 0.6 to 0.7m AHD. Successful modification of this area will be of significant benefit to adjoining residents, an area acknowledged as suffering the most significant impact from biting midge in this locality.

3.5 FINDINGS AND RECOMMENDATIONS

It is unlikely that the recent dramatic increase in biting midge populations in Lake Currimundi could have been foreseen. The slow change to the natural cycle of this

ICOLL occurred over several decades and it wasn't until the lake had remained open for several years that the midge became apparent.

It is also highly likely that the biting midge have always been present in this system and that the natural ICOLL cycle kept their populations at levels that were barely perceptible. Other changes in the catchment that are the result of increasing urban development may have also been beneficial to the midge.

Attempts to minimise the abundance of biting midge have been most successful where the natural cycle of the ICOLL has been replicated through well timed closures. Other measures to vary the elevation and composition of the larval intertidal habitats have also had a degree of success.

Control activities will become more refined over time as knowledge of the midge lifecycle and understanding of the Lake dynamics improves. These control activities must also take into account the wider impact that they may have on the Lake environment and the species therein.

Monitoring and study of the biting midge populations must continue so that the understanding of this species is improved and to guide future control programs. Management of the Lake and surrounds must be mindful of the existence of the midge and wherever possible public works and interventions should aim to minimise its abundance and impact on adjoining urban areas.

The following recommendations are aimed at reducing the abundance of biting midge at Lake Currimundi.

- Continue with the annual late winter/spring closure of Lake Currimundi if winter larval densities indicate that adult populations during spring will be unacceptably high.
- If the Lake closes naturally then the time it is allowed to remain closed should take into account the midge lifecycle. Matters to be considered would include recent larval densities, typical adult midge abundance during that time of year, water quality impacts, risks of upstream flooding etc. In general terms it should be allowed to remain closed for as long as possible.
- Any proposed works in the intertidal zone should take into account the potential biting midge larval habitat. Generally intertidal beaches should be steeper, flat beaches should be lower in elevation and high levels of organic matter should be avoided so that beaches are less suitable as larval habitat. Engineering and environmental constraints would also need to be considered.
- The impact of minor water level variations (egg due to rainfall, partial closures etc) on biting midge is unknown. To assess this impact water level monitoring via a tide gauge or similar should be established.
- Opportunities to manage the lake water levels should be investigated with a view to limiting larval midge survival. For example the strategically timed variation of discharges from Lake Kawana to maintain higher water levels may impact on larval midge.
- Any proposals that increase the tidal range and as a consequence increase the intertidal beach larval habitat should be avoided.

- Landscaping and revegetation works on the foreshore need to consider the harbourage of adult biting midge. In general low dense shady shrubs in areas close to urban development should be avoided and preferred vegetation would include trees with a reasonably high canopy.

CHAPTER 4 – BANK EROSION

The issue of bank erosion is of considerable concern to the Currimundi community. Although the originally proposed tasks for the Study did not identify bank erosion explicitly, it has been addressed due to the importance placed on it by the community (see Chapter 2).

It is difficult however to identify a specific cause of this as bank erosion occurs naturally and can be exacerbated by a number of aspects of urban development. In the following section details of the community's concerns will be discussed and various management options for the Lake will be presented. This material relates to the causes of erosion and management options paraphrased from a report on Saltwater Creek on the Gold Coast (Robertson et al 2005). This information can be found in Volume 2 – Appendix 5.

4.1 BANK STABILITY OPTIONS FOR LAKE CURRIMUNDI

4.1.1 Community Concerns

Erosion along the banks of Lake Currimundi and its adjoining creeks (Figures 8 and 9) is a serious problem and has been of major community concern (see Volume 2 - Appendix 6). The banks are a mixture of sand, silt, coffee rock and sandstone which are easily eroded by the action of tide and wave wash. Consequently the roots of trees have become exposed causing them to fall into the water and large sections of bank are lost from the parks and bushland bordering the lake. Although the community has accepted that bank erosion is a natural process many have questioned whether the current rate of erosion is occurring at its natural rate or is being sped up by yearly midge control operations, boat wash, increased use of walkways and the removal of fallen trees (Figure 10).

Figure 8: Bank erosion along Lake Currimundi

Figure 9: Fallen tree within Lake Currimundi

In the 2008 community survey, 21% of respondents stated that boating issues was a priority issue for Lake Currimundi (see Volume 2 – Appendix 4).

Figure 10: Wash created from boat within Lake Currimundi

In the final community workshop held 11 March, 2008 the community discussed the issue of bank erosion. Below is a table outlining the community perception of the causes of bank erosion and their suggested solutions.

BANK EROSION OF LAKE CURRIMUNDI

Perceived Causes

- More water coming from Lake Kawana
- Weir – pumping at 80ML/day rate
- Increased recreation – walking along eroded banks
- Loss of riparian vegetation
- Closing of the lake causing bank slumping
- Boat wash
- Population increase
- Inappropriate entrance openings causing erosion damage to dunes
- Lack of enforcement of boat speeds

Community Suggested Solutions

- Revegetation of riparian zone
- Limit frequency of openings and investigate position of opening
- Rock/sand bag wall, soft engineering structures
- Control water coming from the weir
- Stop the removal of fallen trees
- Bioengineering techniques such as tree snagging
- Banning of motorised boats
- Speed cameras/enforcement of boat speeds
- Education of councillors and increased funding
- Run trials on smaller affected areas
- Education of lake front community members

Figure 11: Exposed coffee rock at entrance to Lake Currimundi

4.1.2 Options for Management of Bank Erosion in Lake Currimundi

From the input from the community and previous studies it is clear that bank erosion has been ongoing for many decades either due to natural causes or through modification to the Lake as a result of urbanisation. It is well documented that natural systems suffer from bank erosion due to stream meandering, intermittent opening and closing, and scour due to extreme flooding events. However, the concerns of the community over the current situation require an identification of causes for erosion under the modified state of the lake. Unfortunately no single cause has been identified through the review of earlier studies or from comments by the community. The cause of the erosion is most likely a combination of a number of factors including those identified by Witheridge (2006):

- inappropriate vegetation
- exposure of dispersive sub soil
- redirection of flow at key locations
- recreational impacts – boating and infrastructure
- instability with soil saturation when water level is elevated

There is certainly clear evidence of bank instability in 1989 when the lake was closed for most of the year resulting in a lot of trees falling.

Although scour velocities have not been monitored the modelling work done as part of this study has indicated peak average velocities of 0.4m/s on the flood tide and 0.2m/s on the ebb tide during the event monitoring in June 2008. These velocities are high enough to cause scour in sandy soil in their own right. Of course any redirection or concentration of flow due to changes in the waterway will result in localised scour as has been observed in a number of locations. Although the major dredging activity in 2004 would have created an acute bank stability problem it is considered that the changes that occurred at that time were acute and that it is the more persistent causes of bank instability outlined above that are of more concern.

In particular, although the development in the catchment and the transition of the Lake from an ICOLL to an estuary is no doubt causing increased flows, the main issues are that the banks have been modified from their natural state for recreational and visual amenity purposes, and that there is a significant level of boating activity.

4.1.2.1 Riparian Vegetation

Riparian vegetation plays an important role in creating bank stability. As the lake has been urbanised the natural bank vegetation has either been removed to make way for grassed areas or hard surfaces, or for visual amenity. Studies of ICOLLS in NSW (O'Connell and Wiltshire (2005)) show that with the removal of native vegetation, there is no natural recovery process of re-colonisation following one of the other erosion processes. The lack of appropriate riparian vegetation along Lake Currimundi has resulted in decreased bank stability allowing other erosion causing factors to be exacerbated. It is recommended that there be a riparian vegetation rehabilitation program developed consistent with other environmental values.

4.1.2.2 Boat Wash Management

Although boat wash is not the primary cause of bank erosion within Lake Currimundi, it is obvious that it is still having a detrimental effect on the lake's banks. As a result, there are three management techniques to reduce these adverse impacts.

Speeds and Signage

The current speed limit within Lake Currimundi is 6 knots. This speed limit is signalised and enforced through the use of signs. The wash created by many boats travelling at 6 knots is still significant enough to have an adverse impact on the lake's bank. A small reduction in speed can lead to a large reduction in the amount of wash created and its subsequent impact on the bank. As such, it is recommended that signage within Lake Currimundi be changed to that shown in Figure 25, where the speed limit is set to a no wash zone. This will require boats to travel at a speed at which they produce little or no wash. It may not be possible for some boats to produce zero wash even when travelling at very slow speeds; however the impact of waves on the creek bank would be reduced by any reduction in boat speeds.

Community Knowledge

The community members raised concerns during the workshops in relation to boats not obeying the speed limit within Lake Currimundi. Whilst the majority of the boats observed in Lake Currimundi were obeying the speed limit, observations were made of speeding boats. This was also shown in the community survey where almost 16% of the respondents stated that they travelled faster than 6 knots within the creek. It is important that the Lake Currimundi community understand the lake's fragile condition and the damage that is caused by boat wash and in particular, speeding boats.

It is recommended that a newsletter be distributed to the Lake Currimundi community outlining the importance of obeying the speed limits within the creek. This will place some of the responsibility of the management of erosion back on to the community. The aim of the newsletter is to highlight the fragile nature of the environment in Lake Currimundi, discuss and explain the new "no wash" signs that are to be located along the creek and to explain the importance of obeying these new signs when traversing the creek.

Figure 12: No wash speed signage

Enforcement of the Speed Limit

Also raised at the community meeting was the suggestion of the use of water police to monitor and enforce the speed limit set within the creek. This type of management technique would only be effective whilst the police were monitoring the creek. Whilst it cannot be ignored, it is not highly prioritised as a management technique.

4.1.3 Erosion Management recommendations

There are three key recommendations that come from the overall assessment of bank erosion. In general the issue of bank erosion is one that can benefit from modification to riparian management practices, but which will also be reactive to other Lake management strategies dealing with water quality and biting midge. The recommendations are:

- Development of a lake foreshore management plan including riparian vegetation rehabilitation, structural bank stabilisation where appropriate and boat wash management strategies.
- Inclusion of community involvement in monitoring of bank erosion and environmental and other causal factors. This information should be integrated into the operation of the AMF.
- If absolutely necessary to help protect a key asset or infrastructure, the installation of a more natural looking hard structure such as Rock Rip Rap is recommended. Rock Rip Rap would be a more suitable structure as it is line with the area and would be suitable for most areas located along the Lake especially on the outer bends where the most significant erosion occurs.

In the development of this plan the recommendations for midge control should be taken into account. These include the need for steeper banks, taller trees and minimisation of exposed tidal flats. All of these are consistent with the character of the riparian zone prior to urbanization and the development of more estuarine conditions in the Lake. An overview of realistic bank stabilization options including natural re-vegetation was given in Table 1 of Volume 2 - Appendix 5.

CHAPTER 5 – ANALYSIS OF EXISTING WATER QUALITY DATA [1]

5.1 INTRODUCTION

An important task set for this study, was to analyse all existing data on water quality in order to establish any trends and/or correlation with environmental parameters such as rainfall, or with modifications to the waterway. An objective for the Study was to develop a first order model which relates the water quality outcomes with environmental and other parameters which influence the water quality (See Appendix 3). Although neural network techniques were flagged in the proposal, other methods (mainly General Additive Models (GAMS) – see Chapter 6 – have been used. Another objective set for the study was to develop an operational system to link with the water quality monitoring system. The intention here was to integrate the water quality monitoring into the Adaptive Management Framework through feed-back of data into the lake management operating protocols. Throughout the study, the difficulties of establishing a real-time water quality monitoring system have been identified, and consequently, the feed-back of water quality data will be demonstrated through the adaptive application of the first order modelling (eg. GAM) to the operating protocols (see Chapters 6 and 10).

5.1.1 Aims

- To evaluate existing data of water quality indicators for the Lake Currimundi system, as collected by council and to determine the degree of compliance of the monitored water quality indicators with the relevant guidelines.
- To evaluate whether the water quality indicators have undergone any changes since before and after early 2005, at which time the mouth of the system was dredged and also pumping of water from Lake Kawana commended.
- To evaluate existing data of water quality indicators for the Lake Currimundi system, as collected by community members and to determine the degree of compliance of the provided data with the relevant guidelines.
- To evaluate the similarities and differences between the community data and the council data.

5.2 BACKGROUND

Lake Currimundi is a coastal lagoon, which is generally open to the ocean. Development in the catchment in the 1980s and 1990s has seen the construction of three canals that now form part of the tidal waterway of the Lake. The Lake has also recently been connected to the artificial Lake Kawana via a weir set at 0.6 AHD.

Concerns have been raised that the connection to Lake Kawana, combined with the natural closing of the lake mouth to the ocean may have a detrimental impact on water quality indicators. The acceptable values for water quality indicators are specified by the Queensland Environmental Protection Agency (EPA) and depend on the nature of the system. The Lake Currimundi system falls into the category of “Mid-estuarine and tidal canals, constructed estuaries, marinas and boat harbours” and the associated guidelines are presented in Figure 13.

[1] This Chapter has been prepared by Dr Aaron Weigand and Associate Professor Thomas Schlacher from the University of the Sunshine Coast.

Compliance against a second set of guidelines is also presented in this report. These guidelines are specific to water bodies in the Caloundra City Council area, and are presented in Figure 14. Council has advised that the "water type" applicable for this study is "Enclosed Coastal", which is almost identical to the water type "Enclosed Coastal – Constructed Waterways and Lakes", which is applicable to the upper reaches of the canal system.

Table 2.5.1.1: Regional guidelines for physico-chemical indicators – South-east region

South-east region water type	Physico-chemical indicator (refer Appendix E) and guideline value[9] (slightly – moderately disturbed systems)															
	Amm N	Oxid N	Org N[6]	Total N	Filt R P	Total P	Chl-a	DO (% sat[8]) [1,2,3]		Turb	Secchi	SS	pH [4,5]		Salinity	Temperature[10]
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	lower	upper	NTU	M	mg/L	lower	upper		°C
Open coastal	6	3	130	140	6	20	1.0	95	105	1	5.0	10.0	8.0	8.4	n/a	Managers need to define their own upper and lower guideline values, using the 80th and 20th percentiles, respectively, of ecosystem temperature distribution (ANZECC 2000)
Enclosed coastal	8	3	180	200	6	20	2.0	90	105	6	1.5	15	8.0	8.4	n/a	
Mid-estuarine and tidal canals, constructed estuaries, marinas and boat harbours	10	10	280	300	6	25	4.0	85	100	8[8]	1.0[8]	20[8]	7.0	8.4	n/a	
Upper estuarine	30	15	400	450	10	30	8.0	80	100	25[8]	0.5[8]	25[8]	7.0	8.4	n/a	
Lowland streams	20	60	420	500	20	50	5.0	85	110	50	n/a	6	6.5	8.0	See Appendix G	
Upland streams	10	40	200	250	15	30	2.0	90	110	25	n/a	6	6.5	8.2	See Appendix G	
Freshwater lakes/ reservoirs	10	10	330	350	5	10	5.0	90	110	1–20	nd	nd	6.5	8.0	See Appendix G	
Wetlands [7]	nd	nd	nd	nd	nd	Nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	

Note 1	Note that DO guidelines (% saturation) for freshwaters should only be applied to flowing waters, including those with significant subsurface flows. Stagnant pools in intermittent streams naturally experience values of DO below 50% saturation.
Note 2	DO Guideline values in the Table above apply to daytime conditions. Lower values may occur at night but this should not be more than 10 % –15% less than daytime values.
Note 3	DO values as low as 40% may occur in estuaries for short periods following material inflow events after rainfall. DO values consistently <50% are likely to significantly impact on the ongoing ability of fish to persist in a water body. DO values <30% saturation are toxic to some fish species. These DO values should be applied as absolute lower limit guidelines for DO – see also section 4.2. Very high DO (supersaturation) values can be toxic to some fish as they cause gas bubble disease.
Note 4	During flood events or nil flow periods, pH values should not fall below 5.5 (except in wallum areas) or exceed 9.
Note 5	In Wallum areas, waters contain naturally high levels of humic acids (and have a characteristic brown ti-tree stain). In these types of waters, natural pH values may range from 3.6-6.0.
Note 6	During periods of low flow and particularly in smaller creeks, build up of organic matter derived from natural sources (e.g. leaf litter) can result in increased organic N levels (generally in the range of 400 to 800µg/L). This may lead to total N values exceeding the QWQG values. Provided that levels of inorganic N (i.e. NH3 + oxidised N) remain low, then the elevated levels of organic N should not be seen as a breach of the guidelines, provided this is due to natural causes.
Note 7	For Wetlands, see ANZECC 2000 guidelines.
Note 8	These guideline numbers apply to estuaries less than 40km in length. Longer estuaries have naturally higher turbidity levels (and corresponding higher suspended solids and lower Secchi values) due to the longer retention times for suspended particulates and also to the continual re-suspension of fine particles by high tidal velocities. Values are variable and site specific. However, most values are <100NTU and very few values are >200NTU.
Note 9	For information on general application of these guideline values, on their application under different flow conditions and on approaches to assessing pulse inputs of pollutants – see Section 4 and Appendix D of the QWQG.
Note 10	Temperature varies both daily and seasonally, it is depth dependent and is also highly site specific. It is therefore not possible to provide simple generic water quality guidelines for this indicator. The recommended approach is that local guidelines be developed. Thus, guidelines for potentially impacted streams should be based on measurements from a nearby streams that have similar morphology and which are thought not to be impacted by anthropogenic thermal influences. From an ecological effects perspective, the most important aspects of temperature are the daily maximum temperature and the daily variation in temperature. Therefore measurements of temperature should be designed to collect information on these indicators of temperature and, similarly, local guidelines should be expressed in terms of these indicators. Clearly, there will be an annual cycle in the values of these indicators and therefore a full seasonal cycle of measurements is required to develop guideline values.

General abbreviations
nd = no data; n/a = not applicable

Figure 13: Extract from "Queensland Water Quality Guidelines 2006", Qld EPA

Table 15 – Water Quality Objectives within Caloundra City Council Area

WATER QUALITY OBJECTIVE	WATERBODY TYPE: UPLAND FRESHWATER	LOWLAND FRESHWATER	FRESHWATER LAKES	UPPER ESTUARINE	MID-ESTUARINE	ENCLOSED COASTAL	OPEN COASTAL	ENCLOSED COASTAL – CONSTRUCTED WATERWAYS AND LAKES	ENCLOSED COASTAL – PUMICESTONE PASSAGE
Physical-Chemical Indicators									
Temperature Degrees Celsius °C	14.2 – 23.0	18.9-23.2	18.9-23.2	18.6-27.5	19.6-27.2	18.7 – 26.0	Ocean 20.0-24.6 Open Coastal 22.7-28.5	18.7 – 26.0	18.7 – 26.0
pH	7.43-8.22	7.26-8.08 7.45-8.37	7.26-8.08 7.45-8.37	7.60-8.07	8.06-8.44	8.13-8.38	Ocean 8.21-8.46 Open Coastal 8.17-8.51	8.13-8.38	8.13-8.38
Conductivity (mS/cm)	0.078 – 0.112	Mary R (244.1kms) 0.240-0.388 Mary R (91.0 kms) 0.348-0.646	Mary R (244.1kms) 0.240-0.388 Mary R (91.0 kms) 0.348-0.646	10.28-24.96	37.40-52.70	48.62-55.25	Ocean 53.65-54.45 Open Coastal 53.95-54.73	48.62-55.25	48.62-55.25
Dissolved Oxygen DO* (% saturation)	98-108	84-104 87-102	84-104 87-102	89 - 98	85 - 96	88-95	Ocean 92-98 Open Coastal 93-98	88-95	88-95
Turbidity* (NTU)	1.0-4.0	6.0-18.0	6.0-18.0	5.0-20.0	3.0-5.0	2.0-8.0	Ocean 0-1.0 Open Coastal 0 -3.0	2.0-8.0	2.0-8.0
Secchi Depth* (m)	0.2-0.5	1.0-2.0 0.3-0.8	1.0-2.0 0.3-0.8	0.4	0.4-0.9	0.9-2.0	Ocean 5.0-11.0 Open Coastal 1.2-5.0	0.9-2.0	0.9-2.0
Suspended Solids* (mg/L)	1.0-3.0	1.0-6.0	1.0-6.0	5.0-32.0	4.0-13.0	5.0-17.0	Ocean 1.0-10.0 Open Coastal 4.0-7.0	5.0-17.0	5.0-17.0
Nutrients									
Organic Nitrogen OrgN* (ug/NL)	50.0-200.0	280.0-500.0	280.0-500.0	100.0-380.0	50.0-240.0	100.0-200.0	Ocean 50.0-100.0 Open Coastal 50.0-100.0	100.0-200.0	100.0-200.0
Ammonia* NH4 (ug/NL)	3.0-6.0	6.0-10.0	6.0-10.0	10.0-42.0	10.0-27.0	6.0-13.0	Ocean 8.0-15.0 Open Coastal 6.0-15.0	6.0-13.0	6.0-13.0
Oxidised Nitrogen NOx* (nitrate / nitrite) (ug/NL)	3.0-20.0	1.0-130.0	1.0-130.0	1.0-25.0	2.0-10.0	2.0-4.0	Ocean 1.0-8.0 Open Coastal 1.0-4.0	2.0-4.0	2.0-4.0
Total Nitrogen N* (ug/L)	320	300	750	470	300	230	120	400	220
Dissolved Reactive Phosphorus DRP* (ug/PL)	13.0-22.0	8.0-34.0	8.0-34.0	10.0-21.0	2.0-6.0	3.0-12.0	Ocean 4.0-8.0 Open Coastal 2.0-6.0	3.0-12.0	3.0-12.0
Total Phosphorus TP* (ug/PL)	15.0-35.0	25.0-69.0	25.0-69.0	27.0-60.0	10.0-20.0	18.0-32.0	Ocean 9.0-30.0 Open Coastal 8.0-20.0	18.0-32.0	18.0-32.0
Biological Indicators									
Chl - a* (ug/L)	0.6-1.7	2.8-9.0	2.8-9.0	1.0-5.7	0.7-2.9	1.1-2.9	Ocean 0.3-1.3 Open Coastal 0.3-1.0	1.1-2.9	1.1-2.9
Microbiological (organisms / 100mL)	Median <150 faecal coliforms or <35 enterococci	Median <150 faecal coliforms or <35 enterococci	Median <150 faecal coliforms or <35 enterococci	Median <150 faecal coliforms or <35 enterococci	Median <150 faecal coliforms or <35 enterococci	Median <150 faecal coliforms or <35 enterococci	Median <150 faecal coliforms or <35 enterococci	Median <150 faecal coliforms or <35 enterococci	*Most probable Number (MPN) of Coliforms <14/100mL. No more than 10% of samples >43MPN/100mL=*
Delta 15 Nitrogen** (parts per thousand) *Data to be added from Currimundi and Mooloolah River reports*								N/A	<4
Nuisance organisms	*Algae <20,000 cells/mL No excessive macrophyte growth*	*No excessive macrophyte growth*	*Algae <20,000 cells/mL No excessive macrophyte growth*	*No excessive macrophyte growth*	*Algae <20,000 cells/mL No excessive macrophyte growth*	*Algae <20,000 cells/Ml No excessive macrophyte growth*	*Algae <20,000 cells/mL No excessive macrophyte growth*	*Algae <20,000 cells/mL No excessive macrophyte growth*	*Algae <20,000 cells/mL No excessive macrophyte growth*

Figure 14: Extract from "Environmental Protection (Water) Policy 1997: Mooloolah Stream Environmental Values and Water Quality Objectives Basin No. 141 (part) including all tributaries of the Mooloolah River" ENVIRONMENTAL PROTECTION AGENCY March 2006

5.3 ANALYSIS OF COUNCIL MONITORING DATA

5.3.1 Data Characteristics

These data were provided by Griffith University as being water quality monitoring data collected by Caloundra Council and are therefore considered in this analysis to have been validated. All cases where a datum was quoted as being "less than" some value, the datum was specified as being half of that value.

The water quality indicators that were monitored are presented in Table 1, as well as the corresponding EPA guidelines and the Caloundra-specific water quality objectives (WQO).

Table 1: Water quality indicators monitored by Council, and associated guidelines and WQO's.

Indicator	Units	EPA Min	EPA Max	WQO min	WQO max
Temperature	Celsius			18.7	26.0
Dissolved Oxygen	mg per L				
Dissolved Oxygen	%	85	100	88	95
pH	--	7	8.4	8.13	8.38
Electrical Conductivity	mS per cm			48.62	55.23
Turbidity	NTU		8	2	8
Salinity	ppt				
Faecal Counts	# per 100mL		1000		150 (median)
Ammonia (NH_3)	mg per L		0.01	0.006	0.013
Oxides of Nitrogen (NOx)	mg per L		0.01	0.002	0.004
Total Nitrogen (Ntot)	mg per L		0.3		0.25
Reactive Phosphorus (PO_4)	mg per L		0.006	0.005	0.012
Total Phosphorus (Ptot)	mg per L		0.025	0.018	0.032
Suspended Solids	mg per L		20	5	17

It is clear that the Caloundra-specific WQO are, in many cases, more prescriptive than the general EPA guidelines.

As the council data did not include the percentage of oxygen saturation, this was estimated from the oxygen concentration and temperature with the following empirical equation:

$$DO_{\%} = DO_{mgL^{-1}} \times \frac{T_{^{\circ}C} + 32.72}{482} \times 100$$

The data were collected on an approximate monthly basis from early 2001 to mid 2007 at several monitoring locations, which are presented in Figure 15 and Table 2. Sampling was not standardized with respect to tides. Thus, varying strength of tidal flushing and/or dilution has the potential to confound the interpretation of small-scale spatial and temporal patterns in water quality.

Figure 15: Locations of Council monitoring sites

Table 2: Descriptions of Council monitoring sites

Site ID	Description
8	Currimundi Lake Entrance
5	Lara St - End of S/Water pipe (Storm water drain)
11	Gross Pollutant Trap - Lakeside Retirement Village
13	North Western side of Currimundi Bridge - end of S/Water Pipe
18	Canal Entrance - via Boolagi Drive / Mulloka Esp
16	Pangali Canal - Via Regatta Boulevard end of Mizzen Close
14	North Western side of Tokara Bridge
15	Tokara Canal - via Moondara Drive behind Sewerage Pump Stn 1WB
17	Baroona Canal - via Piringa St behind sewage pump station 1WL
10	Erang St bridge, Southern side
New9	End of Sunjewel Blvd - Behind Sewage Pump Station

5.3.2 General Analysis

5.3.2.1 Bulk Statistics

All water quality data from all sites were grouped together and analysed as a single set, which provided up to 750 values per water quality indicator. Sampling sites 5 and 11 were excluded from the analysis as these sites are a storm water drain and a gross pollutant trap and therefore are not representative of the Lake Currimundi system.

This approach provided a general overview of the nature of the water quality in the system as a whole, without any detail regarding specific locations. The results, with respect to the general EPA guidelines and also with respect to the Caloundra-specific WQO's, are presented in Table 3.

Table 3: Summary statistics of water quality indicators (over all council data)

		All Council Data				EPA Guidelines			Caloundra WQO		
Analyte	Units	Min	Max	Mean	Median	Low	High	% Exceed	Low	High	% Exceed
Temperature	degC	11.8	30.6	22.5	22.7	--	--	--	18.7	26	52
Conductivity	mS/cm	0.52	89.6	44	47	--	--	--	48.62	55.23	81
Salinity	ppt	3.4	37	26	26	--	--	--	--	--	--
pH		4.54	8.9	7.6	7.7	7	8.4	8	8.13	8.38	98
Turbidity	NTU	0	138	9.1	4.9	0	8	29	2	8	42
Dissolved Oxygen	mg/L	0.8	8.85	5.2	5.2	--	--	--	--	--	--
Dissolved Oxygen	%	9.7	92	59	58	85	--	98	88	95	100
Faecal	# per 100mL	0	53000	488	50	0	1000	10	--	150 (med)	0
NH_3	mg/L	0.002	3.04	0.09	0.06	0	0.01	96	0.006	0.013	93
NOx	mg/L	0.001	0.39	0.004	0.016	0	0.01	66	0.002	0.004	91
Ntot	mg/L	0.073	3.31	0.414	0.361	0	0.3	71	0	0.25	84
Preact	mg/L	0.001	0.591	0.012	0.003	0	0.006	21	0.005	0.012	79
Ptot	mg/L	0.001	3.856	0.051	0.019	0	0.025	30	0.018	0.032	66
SuspSolids	mg/L	4	368	118	121	0	20	99	5	17	100
BOD	mg/L	0.1	16.8	1.8	1.5	--	--	--	--	--	

The results (Table 3) clearly show that the Caloundra-specific WQO's are more stringent than the general EPA guidelines. Dissolved oxygen levels are typically lower than both sets of guidelines and nitrogen-based nutrient concentrations are typically higher than the guidelines. It is possible that the elevated nutrients are caused by runoff of fertilizers from the surrounding domestic gardens and the resulting growth (and also decay following death) of algae causes a significant drop in oxygen concentrations.

The high level of suspended solids and turbidity possibly result from land-clearing, urbanization and storm water runoff. High turbidity has numerous ecological impacts, particularly on fish and sea grass, and impacts such as these are likely to be occurring in Lake Currimundi.

5.3.2.2 Spatial and Temporal Variability

It is important to identify if the values of water quality indicators are similar across the entire lake system or whether they vary with respect to specific locations. The temporal patterns of the water quality indicators along with the bulk statistics for each water quality indictor at each site, prior to and after January 2005 are presented in Appendix 7. An analysis of the changes in water quality indicators pre and post January 2005 is provided in section 5.6.2. The analysis provided here is restricted to data collected since January 2005 and excludes sites 5 and 11 as these are not representative of the Lake Currimundi system.

Note that, where relevant, the red horizontal lines indicate the general EPA guideline(s) for that water quality indicator. It must be noted that not too much emphasis should be placed on individual sites and or spatial patterns because of four reasons: (1) the system is very small in comparison to most estuaries and coastal lagoons, (2) collection of WQ had not been standardized with respect to tidal state, probably confounding spatial patterns, (3) the state of the mouth is likely to play a significant role in determining patterns and (4) catchments influences will equally drive spatial patterns in WQ.

Conductivity and Salinity

Conductivity is a surrogate measure for Salinity. As the Currimundi system is often open to incoming ocean water, it is not surprising to note that the conductivity of the system often approaches the conductivity of sea water (50 mS/cm). Decreased values are often observed at all sites and are most likely due to rain events, which introduce fresh water into the system.

pH

Temporally and spatially, pH is relatively constant.

Turbidity

Turbidity levels are typically below the EPA guideline, but frequently spike to high levels. These are most likely due to rainfall and flooding events and therefore should not be considered against the EPA guidelines.

Dissolved Oxygen

Of particular interest is the percent saturation level of dissolved oxygen. It is clear that concentrations are consistently below the EPA guideline of 85% at all sites. Low DO levels are generally a result of the biological decay of organic matter. There does not appear to have been any significant trend in DO since 2005.

Faecal Coliforms

Faecal Coliforms are introduced into the water body through runoff or direct introduction of sewage and / or animal faeces. The concentrations of these are typically well below the maximum EPA guideline at all sites, but occasional spikes occur, most probably as a result of rainfall events. The median value for Faecal Coliforms is below the Caloundra-specific WQO for this indicator.

Nutrients – Nitrogen

Ammonia, oxides of nitrogen (nitrate and nitrite) and totals nitrogen (which includes “bound” nitrogen) are typically higher than the EPA guideline at all sites. These nutrients are typically introduced into water bodies in runoff from construction sites, roads and domestic gardens (fertilizers) and also sewerage facilities. The high concentrations in the Lake Currimundi system indicate that the system has potential to turn eutrophic, but other factors, such as high turbidity, help prevent this.

Nutrients – Phosphorus

Reactive phosphorus and total phosphorus are both typically below the EPA guidelines, but do occasionally spike, most probably as a result of rainfall events.

Suspended Solids

Suspended solids are high at all sites and show little temporal variation. However, a small decline in suspended solids is observed in mid 2007 at sites 14, 15, 16 and 18, which are all related to Tokara Canal. This observation is reflected (albeit marginally) in the turbidity data.

5.3.3 Before and After January 2005

As mentioned in the introduction, concerns have been raised that the connection of Lake Kawana to the Lake Currimundi system (Figure 16), combined with the natural closing of the Lake Currimundi mouth to the ocean, can have a detrimental impact on water quality indicators in the Lake Currimundi system.

The bulk statistics for each water quality indicator at each site, separated into pre- and post-January 2005 periods, are provided in Appendix 7. A *t*-test was performed to compare pre- and post-January 2005 levels to evaluate if a significant change had occurred for each water quality indicator for each site. A “p-value” less than 0.05 indicates a 95% certainty that a significant change had occurred. Table 5 summarises all water quality indicators and locations where a significant change in the water quality indicator was observed. Note that for this evaluation, sites 5 and 11 have been included. “N low” and “N high” indicate the number of times the general EPA water quality guideline was exceeded at that location over all the data. The Caloundra-specific WQO was not assessed as it has already been determined that this is exceeded a majority of the time.

Figure 16: Weir between Lake Kawana (distant) and Lake Currimundi System (foreground)

Table 4: All water quality indicators and sites where a significant change has been observed

Water Quality Indicator	Sites	Description of Change in Median Value
Conductivity	**8, 13, 18, 16, 14, 15, 17**	**Up to 25% decrease**
Dissolved Oxygen	**All except 5 and 11**	**Up to 44% increase**
Reactive Phosphorus	**5**	**72% decrease**
Suspended Solids	**18, 16, 14**	**Up to 18% decrease**

Table 5 shows that, whether or not the changes are statistically significant, the values for nearly all water quality indicators appear to have improved since January 2005. Note that for all indicators, except dissolved oxygen and pH, a decrease (negative % change in mean magnitude) is a desired outcome. The percent exceedances denote proportion of measurements that breach general guideline values. The "ncv" denotes that "no critical value" is specified in the guidelines.

Table 5: Comparison of compliance with EPA guidelines pre and post January 2005 (whole system)

	% Change in Mean Magnitude	% Change in Median Magnitude	% Exceedences Before Jan2005	% Exceedences After Jan2005
Temperature	3	2	ncv	ncv
Conductivity	-11	-18	ncv	ncv
Salinity	--	--	ncv	ncv
pH	1	0	11	3
Turbidity	3	-12	27	32
DO mgL^{-1}	26	35	ncv	ncv
DO %	28	35	100	94
Faecal Coliforms	-27	0	10	10
NH_3	-23	-25	98	91
NOx	-20	-22	69	59
Ntot	-1	10	64	84
Preact	-66	-33	21	20
Ptot	-65	-8	32	24
Suspended Solids	-9	-11	100	99
BOD				

*ncv: no critical value in the general EPA guidelines

In most cases, improvement in water quality indicators have been enough to reduce the number of exceedances of the guidelines, but several indicators (i.e. suspended solids, total N, dissolved oxygen) continue to regularly breach guideline values, suggesting that water quality is poor and the system is overly turbid, enriched in nitrogen and starved of oxygen.

5.3.4 Key Observations

The following observations are not specific to any of the sampling sites, but reflect the general nature of water quality in the system as a whole.

- Since 2001, temperature, salinity and pH measurements were generally within the EPA guideline levels, but did not fall within the water quality objectives specified for Caloundra City Council.
- Faecal coliforms were generally within the guidelines for secondary exposure, but many observations were significantly higher after significant rainfall events such as storms.
- The systems appear to be enriched with nitrogen: almost all ammonia, oxidized-N and total-N measurements were above the guideline values at most times.
- The total phosphorus and orthophosphate concentrations were within the guidelines most of the time.
- Dissolved oxygen concentrations are consistently lower than guideline values at all sites.
- There does not appear to be any temporal trend for any of the water quality indicators.

The following observations are specific to the comparison of data from before and after January 2005 (which is when the mouth was opened significantly and also regular water transfer from Lake Kawana commenced):

- Water quality indicators show a general improvement in average water quality since the Currimundi mouth was opened and pumping from Lake Kawana commenced. In particular, dissolved oxygen concentrations have increased and nutrient concentrations have decreased.
- Despite the improvement since January 2005, several water quality indicators continue to regularly exceed the water quality guidelines.
- The role of external drivers (e.g. significant rainfall events) is likely to be an important factor in determining water quality of the system and how often guideline values are breached. However, the exact relationship between weather and catchment drivers on the receiving water quality in the system has not been quantified to date. Similarly, the influence of tidal flushing is unknown at present.

5.4 AN ASSESSMENT OF THE WATER QUALITY FOR LAKE KAWANA

The water quality of Lake Currimundi is partially dependent on the quality of the water entering from Lake Kawana. Therefore the aim of this assessment is to evaluate the water quality parameters of Lake Kawana against relevant criteria and against the water quality of Lake Currimundi.

All available data used in this assessment has been pooled so that it is evaluated without reference to specific monitoring sites or dates. The Lake Kawana water quality data were measured from July 2005 to August 2006 and therefore were measured after the inflow into Lake Currimundi commenced. The Lake Currimundi dataset covers the period May 2001 – January 2006 and therefore predominantly covers the period prior to the inflow commencing.

Boxplot analysis of nine analytes were constructed to assess them against both the general EPA water quality guidelines and Caloundra-specific water quality objectives (WQO). This method allows distribution-free comparison of the data by comparing the 95% confidence bands. If the confidence bands do not overlap then the datasets are assumed to be significantly different and if they do overlap then the datasets are assumed to be equal (Cleveland 1993).

The nine analytes assessed were:

- water temperature
- conductivity
- dissolved oxygen
- turbidity
- ammonia
- NOx
- TKN
- DRP
- TP
- faecal coliform count

The boxplots of the analytes are presented in Figure 44.

The mean and distribution of water temperature (ºC) for the two lakes are comparable (Figure 17a). Both lakes are above the WQO minimum temperature threshold but exceed the WQO maximum temperature threshold. There are no EPA guidelines for temperature.

Conductivity (mS cm^{-1}) for the two lakes are not significantly different (Figure 17b), however the median conductivity and distribution in Lake Kawana is clearly lower than for Lake Currimundi. Conductivity levels in Lake Kawana are below both the minimum and maximum WQO values while there are no EPA guidelines for temperature.

Dissolved oxygen (mg l^{-1}) for the two lakes are not significantly different (Figure 17c), however the median conductivity in Lake Kawana is clearly higher than for Lake Currimundi. There are no EPA guidelines or WQO values for dissolved oxygen concentration.

Turbidity (NTU) for the two lakes is not significantly different (Figure 17d). Median values and distribution for the two lakes are comparable. Turbidity levels for Lake Kawana generally meets the requirements of both the EPA guidelines (< 8 NTU) and the WQOs (2 – 8 NTU) although there is indication of exceedance for the high turbidity threshold.

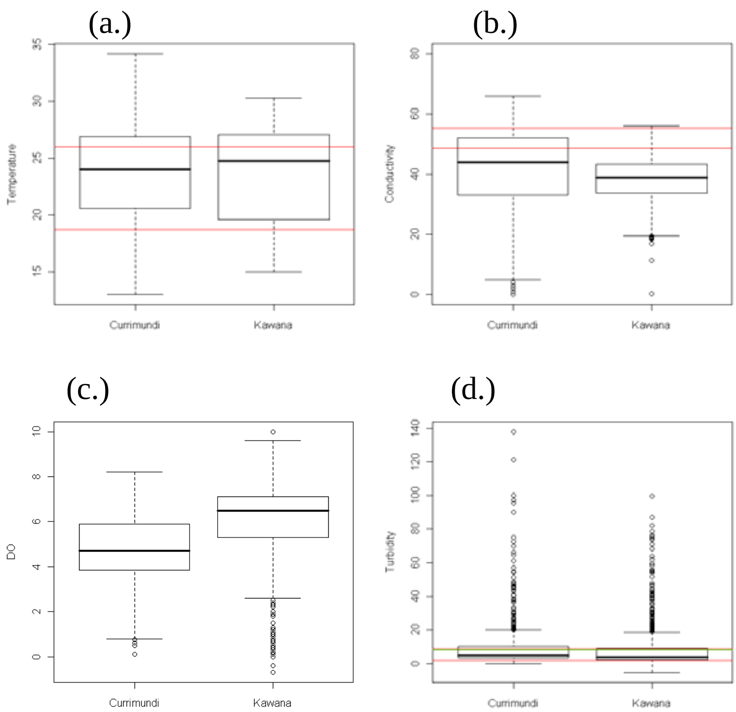
Ammonia (mg l^{-1}) for the two lakes are not significantly different (Figure 17e), however the median concentration for Lake Kawana is clearly higher than for Lake Currimundi. Ammonia concentrations in Lake Kawana exceed both the EPA water quality guideline (0.01 mg l^{-1}) and the maximum WQO (0.013 mg l^{-1}).

NOx concentrations (mg l^{-1}) for the two lakes are not significantly different (Figure 17f), however the median concentration and distribution for Lake Kawana are clearly higher than for Lake Currimundi. NOx concentrations in Lake Kawana exceed both the EPA water quality guideline (0.01 mg l^{-1}) and the maximum WQO (0.004 mg l^{-1}).

TKN concentrations (mg l^{-1}) for the two lakes are not significantly different (Figure 17g), however the median concentration for Lake Kawana is clearly higher than for Lake Currimundi. TKN concentrations in Lake Kawana exceed both the EPA water quality guideline (0.300 mg l^{-1}) and the WQO (0.250 mg l^{-1}).

Dissolved reactive phosphorus (DRP) concentrations (mg l^{-1}) for the two lakes appear significantly different (Figure 17h). DRP concentrations in Lake Kawana exceed the EPA guideline (0.006 mg l^{-1}) but meets the WQOs (0.005 – 0.012 mg l^{-1}). However, the narrow quantile region for Lake Kawana data indicates that the DRP concentrations shown predominantly reflect the detection limits of measurement rather than actual concentrations.

Faecal coliform counts (CFU 100ml^{-1}) for the two lakes are not significantly different (Figure 17i), however the distribution of data for Lake Kawana appears smaller than for Lake Currimundi. Coliform counts in Lake Kawana met the WQO (<150 organisms 100ml^{-1}) and the EPA water quality guideline (1000 organisms 100ml^{-1}).



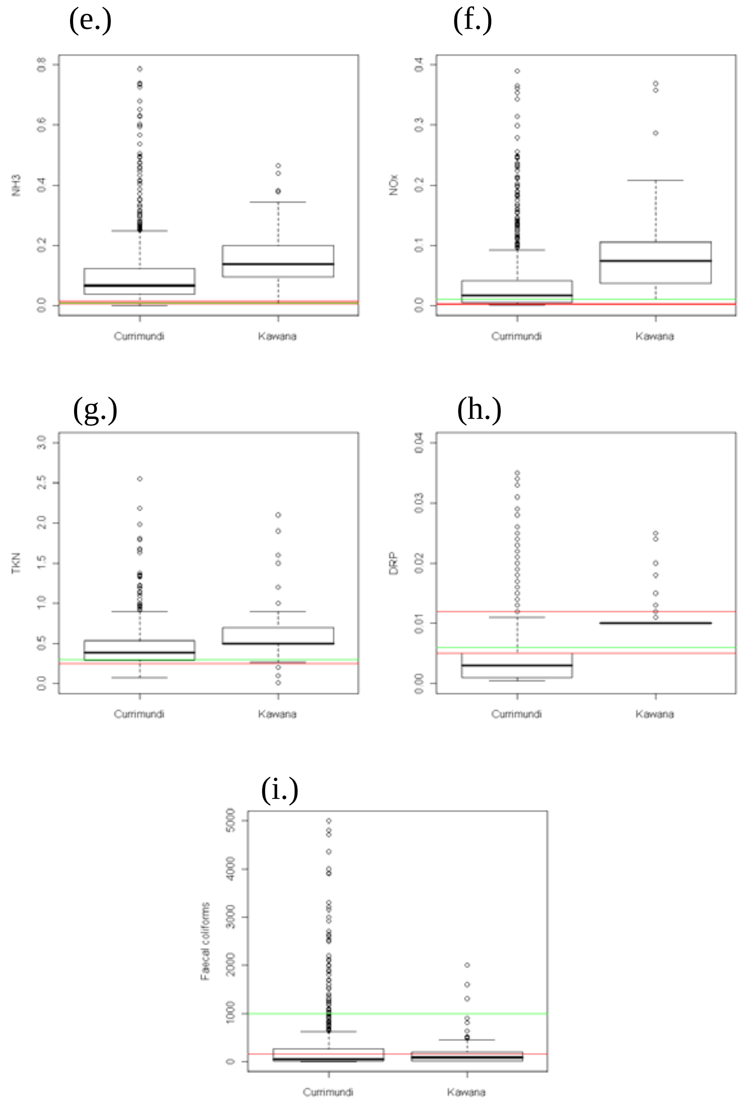


Figure 17: Box plot comparison of analytes in Lake Currimundi and Lake Kawana Water. Red lines indicate Caloundra specific WQO and green lines indicate EPA guidelines.

5.7.1 Discussion and Conclusion

This assessment of the water quality in Lake Kawana highlights that conditions in Kawana are comparable to Lake Currimundi. Boxplot analysis indicated that all of the water quality parameters tested, with the exception of dissolved reactive phosphate (DRP), are not significantly different between Lake Kawana and Lake Currimundi. DRP was found to be higher in Lake Kawana than Lake Currimundi, however it appears that the DRP concentrations in Lake Kawana are limited by the detection limits of measurement and therefore maybe much lower.

These observations seem to explain why no significant improvement was observed in any of the nutrients as outlined in the assessment of an existing water quality dataset compiled by Caloundra City Council (see section 2.3) and also by the generalised additive modelling (see Chapter 6). Furthermore, there is a general failure to meet the EPA guidelines and site-specific WQOs for nitrogen for both Lake Currimundi and Lake Kawana, indicating that there is minimal benefit to nutrient concentrations in Lake Currimundi due to the inflow over the weir.

Faecal coliform counts are comparable between the two lakes even though the GAM assessment indicated a clear (positive) effect of the inflow on coliform counts (see Chapter 6). However, a constraint of this assessment is that it only covers the period after January 2005 (i.e. when inflow commenced) and therefore the water quality of Lake Currimundi (including faecal coliform counts) will be influenced by the water quality of Lake Kawana, especially for monitoring sites near to the weir.

5.5 ANALYSIS OF COMMUNITY MONITORING DATA

5.5.1 Data Characteristics

All these water quality monitoring data were provided by Griffith University as being monitoring data collected by a community group. Community monitoring is important as it builds ownership of the environmental quality and the data may be used to complement data collected by other agencies. It is also important to recognise that because of the inherent ownership of their data, members of the community will often accept findings from the analysis of their own data more readily than findings derived from data collected by other agencies. For this reason, impartial analysis is required to determine the degree of correlation between data sets.

The community data provided for this analysis were sourced from over 20 monitoring sites on and adjacent to the Lake Currimundi system, for the period 2003 to 2007. These data had the following characteristics:

- Accurate site locations such as latitude and longitude were not provided.
- Although monitoring was meant to be monthly, many data were missing from the time series.
- Monitoring at different sites occurred on different days.
- Some monitoring sites have only one or two measurements in total.
- Some of the values were impossibly high, possibly a result of typographical error.
- The stated units for conductivity were μScm^{-1}, when the data were clearly $mScm^{-1}$.
- Salinity data are discrete until 2007

In response, the following corrections were made to the data:

- Obvious outliers were deleted from the data set.
- All cases where a datum was quoted as being “less than” some value, the datum was specified as being half of that value.

As the community data did not include the percentage of oxygen saturation, this was estimated from the oxygen concentration and temperature with the following empirical equation:

$$DO_{\%} = DO_{mgL^{-1}} \times \frac{T_{^\circ C} + 32.72}{482} \times 100$$

5.5.2 General Analysis

The intermittent nature of the data makes a rigorous spatial and temporal analysis impossible. However, these data are valuable because, as a grouped set, they can provide a good indication of water quality in the entire lake system as a whole over the period of the data.

Bulk Statistics

All water quality data from all sites were grouped together and analysed as a single set, which provided up to 676 values per water quality indicator. This approach provided a general overview of the nature of the water quality in the system as a whole, without any detail regarding specific locations. The summary bulk statistics are presented in Table 6 while histograms for each dataset per water quality indicator are presented in Appendix 7.

These results clearly show that DO levels are typically lower than the EPA guideline of 85% and that turbidity levels are also often higher than the EPA guidelines. The high level of suspended solids and turbidity possibly result from land-clearing, urbanization and storm water runoff. High turbidity has numerous ecological impacts, particularly on fish and sea grass, and impacts such as these are likely to be occurring in Lake Currimundi.

Table 6: Summary statistics of water quality indicators (over all community data)

		Guideline		All Community Data				
Analyte	**Units**	**Low**	**High**	**Min**	**Max**	**Mean**	**Median**	**% Exceed**
Temperature	degC	--	--	10.5	34.2	23.7	23.9	--
Conductivity	mS/cm	--	--	0	66	37.9	43	--
Salinity	ppt	--	--	0	40	25.2	30	--
pH		7	8.4	2.6	9.2	7.55	7.8	17
Turbidity	NTU	0	8	0	172	10.8	7	43
Dissolved Oxygen	mg/L	--	--	0	10.1	5.84	6.1	--
Dissolved Oxygen	%	85	--	0	133	68	71	86

Temporal Variability

The value of each water quality indicator was plotted against time on a single axis, irrespective of the site to which the datum pertains. The EPA guideline values are presented as red, horizontal lines. These plots are presented in Figure 18. The statistics presented in Table 6 regarding the proportion of exceedances of the EPA guideline are reflected in these time-series plots.

The seasonal variability of the water quality indicators is clear despite the data-points being from a multitude of monitoring sites. The "vertical grouping" of the data-points indicates that the actual values, as well as the variability, of the water quality indicators are similar across the lake system.

Visual inspection of these plots does not elucidate a clear trend, either increasing or decreasing, in any of the water quality indicators over the Lake Currimundi system as a whole.

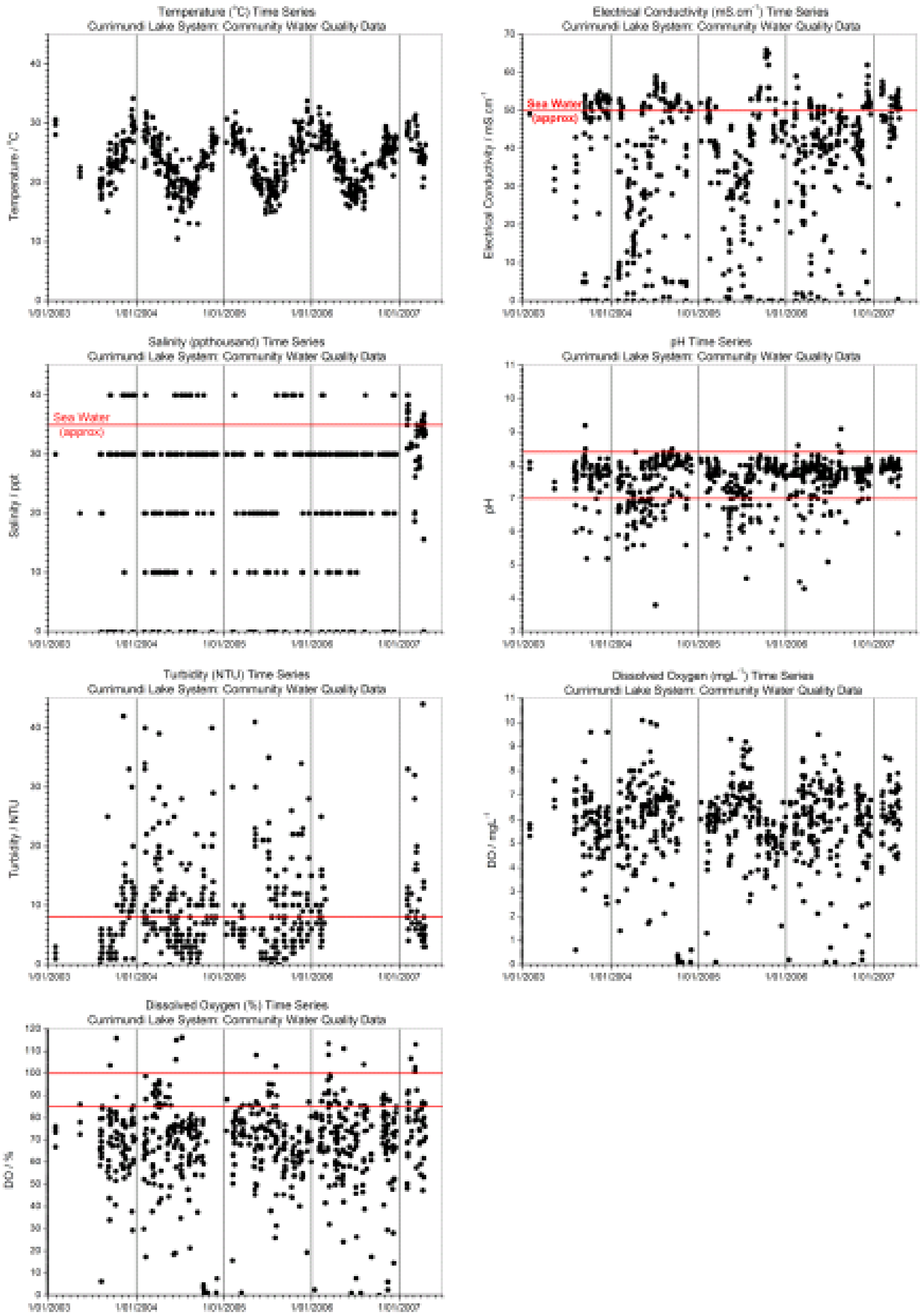


Figure 18: Time-series plots of all water quality data (community data). The EPA guideline values are presented as red, horizontal lines.

Comparison of Community Data against Council Data

Bulk Statistics

To compare the bulk statistics of the Council data against those of the community data, the statistics presented in Table 1 and Table 6 are combined in Table 7 for ease of comparison. These bulk statistics represent the water quality of the entire Lake Currimundi system, approximately over a period of 5 years.

Table 7: Comparison of summary statistics of council data against community data

		Guideline		All Council Data					All Community Data				
Analyte	Units	Low	High	Min	Max	Mean	Median	% Exceed	Min	Max	Mean	Median	% Exceed
Temperature	degC	--	--	10	30.85	22.5	22.6	--	10.5	34.2	23.7	23.9	--
Conductivity	mS/cm	--	--	0.3	89.6	44	47	--	0	66	37.9	43	--
Salinity	ppt	--	--	3.4	37.24	26	26.4	--	0	40	25.2	30	--
pH		7	8.4	4.54	8.9	7.6	7.7	10	2.6	9.2	7.55	7.8	17
Turbidity	NTU	0	8	0	138	9.1	5	30	0	172	10.8	7	43
Dissolved Oxygen	mg/L	--	--	0.1	8.85	4.9	4.9	--	0	10.1	5.84	6.1	--
Dissolved Oxygen	%	85	--	1	92	56	56	98	0	133	68	71	86
NH_3	mg/L	0	0.01	0.002	3.043	0.099	0.062	96	N/A	N/A	N/A	N/A	N/A
NOx	mg/L	0	0.01	0.001	0.923	0.046	0.020	70	N/A	N/A	N/A	N/A	N/A
Ntot	mg/L	0	0.3	0.073	3.49	0.448	0.377	74	N/A	N/A	N/A	N/A	N/A
Preact	mg/L	0	0.006	0.001	0.591	0.014	0.003	29	N/A	N/A	N/A	N/A	N/A
Ptot	mg/L	0	0.025	0.001	3.856	0.056	0.021	37	N/A	N/A	N/A	N/A	N/A
Chlorophyll-a				N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

It is important to note that the two sets of data are composed of measurements taken over a different time period, at different dates and times, at different locations, with different equipment and by many different people. These factors can influence the data being measured.

Nevertheless, the two sets of data result in very similar statistics and conclusions regarding exceedances of the EPA guidelines, for the limited range of corresponding water quality indicators that are monitored. Visual comparison of the time series plots of community data and the Council data also indicate that the degree of variability between the two sets of data is similar.

It is concluded that the findings regarding the bulk statistics of the water quality over the entire lake, from the analysis of both sets of data, are consistent between the two datasets for temperature, conductivity, salinity, pH, turbidity and DO.

Regression Analysis

While the bulk statistics from both sets of data are similar, it is important to determine whether both sets of data show similar average temporal variations in the data. Comparison for specific spatial variation is difficult as the monitoring does not always correspond in time.

The average monthly value for each water quality indicator was calculated for each set of data. If the values for each set of data, for each month were identical, the points should not deviate significantly from a 1:1 line and a linear regression of community data against council data would result in an intercept of zero, a slope of 1 and a correlation coefficient of 1. Any deviation from these values indicates some degree of difference between the two data sets. Figure 19 includes two examples of the correlated data and Table 8 contains the regression results for all water quality indicators.

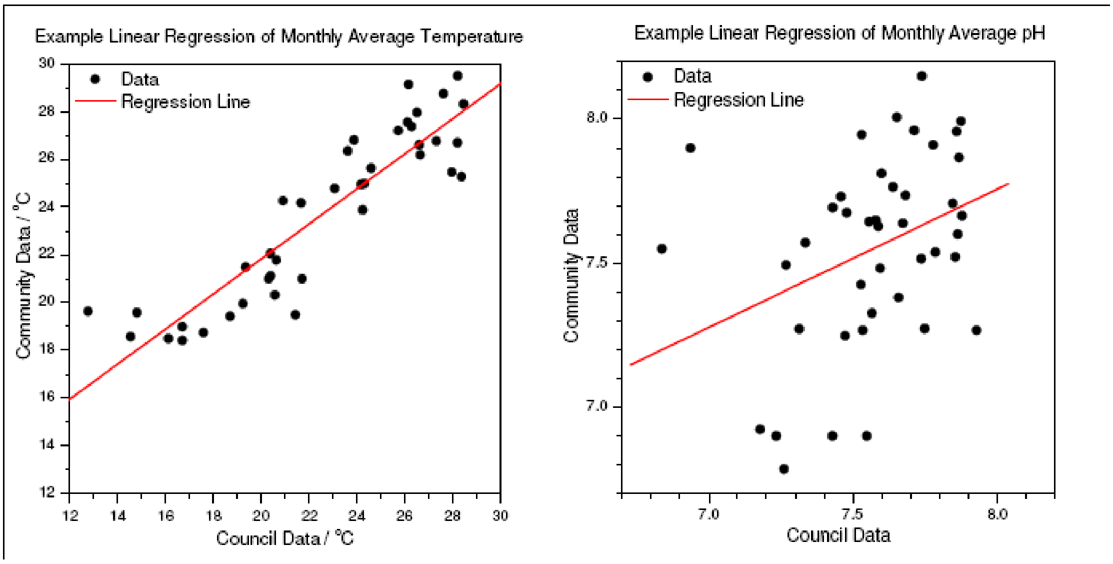


Figure 19: Example Scatterplots and Regression lines of Community Data vs Council Data

Table 8: Linear regression of monthly averages (community data vs council data)

	N data	Slope	Std Dev Slope	Intercept	Std Dev Intercept	R
Temp	40	0.73	0.06	7.2	1.3	0.906
EC	42	0.29	0.11	25.7	4.9	0.375
Salinity	22	0.95	0.19	1.5	4.9	0.742
pH	42	0.48	0.20	3.9	1.5	0.356
Turbidity	31	0.06	0.12	10.1	1.9	0.095
DOmgL	40	0.38	0.20	3.6	1.0	0.296
DOpcnt	40	0.21	0.22	52.3	13.1	0.150

The regression results indicate that only temperature and salinity data have any significant degree of correlation between the two sets of data. This is most likely because these water quality indicators (i.e. temperature and salinity) often do not vary significantly in the short term, whereas all other indicators do have the potential to change rapidly.

It must be noted that not all the regression results may be interpreted in a simplistic manner. For example, the intercept of 7.2ºC for temperature does NOT indicate that the community data are biased absolutely by this amount. This large intercept is actually a result of the data points being clustered at some distance from the y-axis, which causes the effect that any non-unity slope has on the y-intercept to be amplified. Of more significance are the slope statistics, which, if a significant correlation is observed, may be interpreted as relative bias caused by poor calibration in either or both of the datasets.

For the reasons stated above, it can not be concluded whether the community data are more or less accurate or precise than the council data, but it is clear that, with care, the community data can be used to complement the council data, especially with respect to the bulk statistics of the entire system.

5.5.3 Summary

The following observations are not specific to any of the sampling sites, but reflect the general nature of water quality in the system as a whole.

- Since 2001, temperature, salinity and pH measurements were generally within the EPA guideline levels, but did not fall within the water quality objectives specified for Caloundra City council.
- Faecal coliforms were generally within the guidelines for secondary exposure, but many observations were significantly higher after significant rainfall events such as storms.
- The system appears to be enriched with nitrogen: almost all ammonia, oxidized-N and total-N measurements were above the guideline values at most times.
- The total phosphorus and orthophosphate concentrations were within the guidelines most of the time.
- Dissolved oxygen concentrations are consistently lower than guideline values at all sites.
- There does not appear to be any temporal trend for any of the water quality indicators.

The following observations are specific to the comparison of data from before and after January 2005 (which is when the mouth was opened significantly and also regular water transfer from Lake Kawana commenced):

- Water quality indicators show a general improvement in average water quality since the Currimundi mouth was opened and pumping from Lake Kawana commenced. In particular, dissolved oxygen concentrations have increased and nutrient concentrations have decreased.
- Despite the improvement since January 2005, several water quality indicators continue to regularly exceed the water quality guidelines.
- The role of external drivers (e.g. significant rainfall events) is likely to be an important factor in determining water quality of the system and how often guideline values are breached. However, the exact relationship between weather and catchment drivers on the receiving water quality in the system has not been quantified to date. Similarly, the influence of tidal flushing is unknown at present.
- Based on boxplot assessments, there is no significant difference between water quality parameters for Lake Kawana and Lake Currimundi, except for DRP, which is constrained by the detection limits used for Lake Kawana.

The following observations are specific to the comparison between the community data and council data:

- The bulk statistics of both sets of data, for all water quality indicators, are broadly similar.
- The short-term temporal variability between the two sets of data appear to be similar.
- The community data may be used, with care, to complement the council data.

5.5.4 Recommendations

5.5.4.1 Council Monitoring

A) It is recommended that council include the monitoring of chlorophyll-*a* in their suite of water quality indicators. This will provide information regarding the trophic state of the system as well as provide a means to relate temporal changes in variables such as nutrients, BOD and dissolved oxygen.

B) It is recommended that external drivers (state of the mouth, recent rainfall, wind etc) are recorded as part of the monitoring procedure.

5.5.4.2 Community Monitoring

A) The community group has dedicated a significant effort in order to monitor the water quality of the Lake Currimundi system and they should be congratulated for collecting and compiling such a wealth of valuable data. It is also recognised that organising and mobilising a group of volunteers to perform routine sampling in a consistent and scientifically valid manner is a difficult task. However, if this group intends to continue to monitor and collect water quality data for the Lake Currimundi system, it is recommended that they seek expert advice regarding:

- The optimum locations for sampling sites and to ensure that these are selected in consultation with the Council.
- Standardisation of monitoring times and dates (within the group and also with respect to council).
- Validation of the monitoring data.
- Procedures for the storage and communication of these data.

B) As the system is rich in nitrogen-based nutrients, it is also recommended that the community monitoring be expanded to include the measurement of nutrients and also chlorophyll-*a*.

C) It is recommended that external drivers (state of the mouth, recent rainfall, wind etc) are recorded as part of the monitoring procedure.

5.6 INTENSIVE MONITORING PROGRAM, JUNE 2008

5.6.1 Aims

A water quality survey was carried out in June 2008 to address the following aims:

- To evaluate the spatial variability of water quality indicators throughout the lake system.

- To evaluate the changes that occur in the lake system in response to a pulsed freshwater inflow event.
- To evaluate the rate at which the system returns to average conditions (stabilizes).
- To evaluate the spatial variability and depth-profiles of water quality indicators, after the system has stabilized.

5.6.2 Method

Between the 3rd June 2008 and 28th June 2008, twelve trips were made using a small boat to gain access to the sampling sites numbered 1 to 7 as provided in Tables 9 and 10, and illustrated in Figure 21. Sampling site 7 (see Figure 21) was located in Lake Kawana so that the impact of water flow from Lake Kawana into the Currimundi system, with respect to water quality indicators, could be evaluated if necessary.

In order to standardise the sampling across all trips with respect to tide, sampling at site 1 commenced as close to the time of low tide as possible. All sampling progressed "upstream", so that the low tide was "followed". Each sampling run, covering all sites, took approximately two to three hours.

At each site, a Hydrolab Datasonde 4a was used to determine the following in-situ water quality indicators at 0.5m depth increments:

- Temperature degC
- Conductivity μS/cm
- Salinity ppt
- pH
- Chlorophyll-*a* μg/L
- Turbidity NTU
- Dissolved Oxygen mg/L
- Dissolved Oxygen %

Chlorophyll readings were corrected for turbidity bias.

Table 9: Dates and times of sampling trips

TripID	Date	Time of first Sample
1	3/06/2008	13:09
2	5/06/2008	14:58
3	8/06/2008	6:20
4	10/06/2008	7:43
5	12/06/2008	9:44
6	14/06/2008	10:50
7	17/06/2008	12:50
8	19/06/2008	14:15
9	22/06/2008	15:10
10	24/06/2008	6:20
11	26/06/2008	8:09
12	28/06/2008	9:20

Table 10: Locations of sampling sites

SiteID	Deg Min Sec	Deg Min Sec
1	S26 45 52.0	E153 07 55.7
2	S26 45 55.5	E153 07 18.6
3	S26 46 02.0	E153 06 52.9
4	S26 45 37.0	E153 06 59.9
5	S26 45 33.2	E153 07 21.5
6	S26 45 09.7	E153 07 55.7
7	S26 45 11.5	E153 07 17.3

At each site, a filtered and unfiltered sample of water was collected from a depth of 0.5m, held on ice and then frozen until laboratory analysis for nutrients. This analysis was undertaken with a Lachat Quikchem FIA 8000 Series Analyser. Detection error due to variable refractive index, caused by a large range of salinity across samples, was largely eliminated by use of appropriately matched salinity carrier media. These analyses were for nitrate, nitrite, ammonia, total nitrogen, phosphate and total phosphorus. For values below the limit of detection (10 µg/mL), a value of 5 µg/mL was assigned.

Figure 21: Locations of sampling sites (image courtesy of Google EarthTM).

Site 1: middle of sandy lagoon area.

Site 2: approximately 10m west of bridge, centre of water channel.

Site 3: part way up a feeder creek. Water channel is narrow and deep, but is influenced by tides (see Figure 22)

Site 4: centre of channel, immediately opposite second house.

Site 5: end of canal. Surrounded by concrete walls and houses (see Figure 23)

Site 6: end of canal. Surrounded by concrete walls, domestic residences and a small park.

Site 7: Lake Kawana, approx 15m from Weir.

Figure 22: Stormwater drain near sampling site 3

Figure 23: Approaching sample site 5 – Terminal point of Pangali Canal

5.7 RESULTS AND DISCUSSION

5.7.1 Chemistry

The entire set of water quality indicators data is provided in Appendix 7.

5.7.2 Meteorology

One day prior to the study commencing, a significant rain event occurred (Figure 24), which caused considerable freshwater flushing and dilution of the normally-saline system.

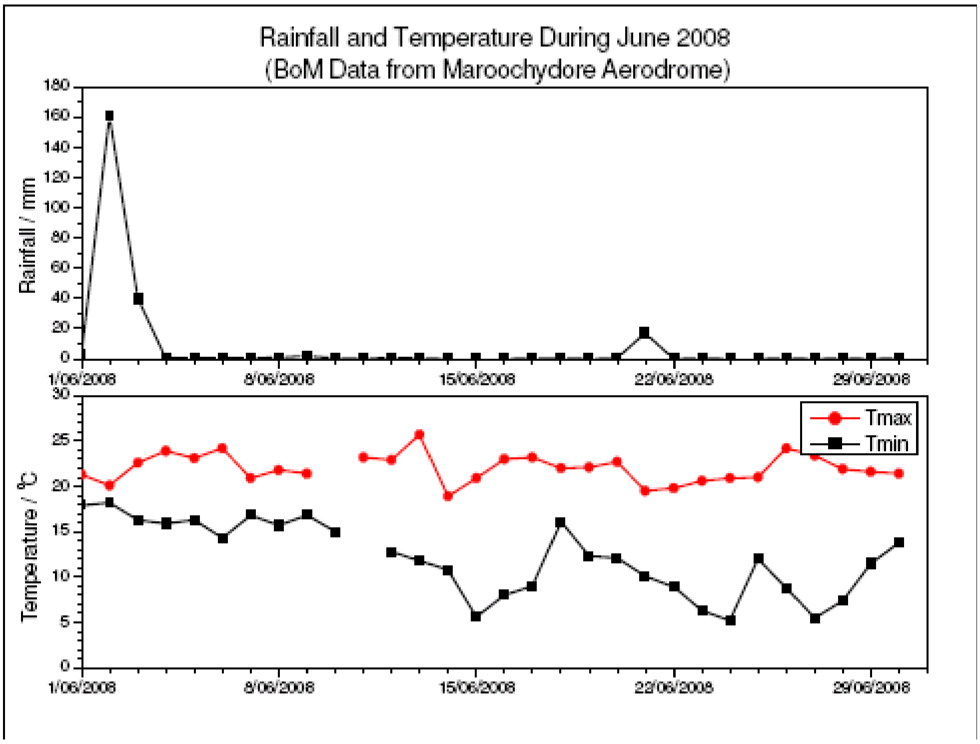


Figure 24: Daily Rainfall and Temperature During Study Period (BoM Maroochydore Data)

5.12.3 General Water Quality during the Study

Note that, because of the significant rainfall event and subsequent freshwater inflow into the system, this analysis is not directly comparable against any analysis that is based on data recorded under "average" conditions.

Although water quality guidelines are not meant to be applied to systems that have undergone a spike event, the data collected through this study are assessed against two sets of guidelines: general EPA water quality guidelines and Caloundra-specific water quality objectives (WQO). Bulk statistics were calculated for data collected at a depth of 0.5m and also for all data at all depths. Only the data collected at a depth of 0.5m were assessed against water quality guidelines.

With respect to the general EPA guidelines, the Currimundi system falls into the category of "Mid-estuarine and tidal canals, constructed estuaries, marinas and boat harbours" and the Regional Guidelines for Physico-Chemical Indicators for the South east region, as specified by the Queensland EPA, were adopted for this analysis.

With respect to the Caloundra-specific WQO, the Currimundi system is divided into three types of water bodies. The limited quantity of data makes an analysis specific to each type of water body statistically meaningless and, as the actual WQO for all three water body types are mostly the same, only the WQO for "Enclosed Coastal" were applied.

All statistics are presented in Table 11 and assessments of the water quality indicators against the guidelines are presented in Table 12. These assessments indicate that nutrient concentrations, compounds of nitrogen in particular, were significantly higher than the water quality guidelines that are recommend for average conditions. This is not considered to be unusual after a significant rainfall event. It is also noted that in all cases, with the exception of reactive phosphorus (phosphate), the Caloundra-specific WQO are exceeded more than the general EPA guidelines.

The histogram distributions of the 0.5m values of the water quality indicators are provided in Appendix 7.

Table 11: Summary statistics of water quality indicators

		0.5m Depth				All Data			
Analyte	Units	Min	Max	Mean	Median	Min	Max	Mean	Median
Temperature	degC	14.8	23.4	19.4	19.5	14.8	23.4	20.1	20.4
Conductivity	uS/cm	1980	47700	34400	38700	1460	54500	43000	45500
Salinity	ppt	0.14	30.3	21.6	24	0.14	36.1	27.9	29.4
pH		5.25	8.17	7.23	7.35	5.25	8.73	7.38	7.5
Chlorophyll-a	ug/L	0	15.2	2.4	1.69	0	20.2	2.62	1.86
Turbidity	NTU	0	53.4	7.56	3.25	0	54.6	6.53	4.3
Dissolved Oxygen	mg/L	6.05	9.87	8.1	8.06	1.82	9.87	7.04	7.52
Dissolved Oxygen	%	74.2	118	98.8	99.5	24.8	118	89.7	95.3
Nitrate-N	ug/mL	11	414	43.1	30	11	414	43.1	30
Nitrite-N	ug/mL	5	20	5.64	5	5	20	5.64	5
NOx	ug/mL	16	419	48.7	35	16	419	48.7	35
Ammonia-N	ug/mL	13	371	92.1	73	13	371	92.1	73
Total N	ug/mL	276	657	428	396	276	657	428	396
Phosphate-P	ug/mL	5	88	11.6	5	5	88	11.6	5
Total P	ug/mL	5	176	17.1	5	5	176	17.1	5

Table 12: Assessment of water quality indicators against water quality guidelines (0.5m depth)

		EPA Guidelines			Caloundra Specific WQO		
Analyte	Units	Low	High	% Exceed	Low	High	% Exceed
Temperature	degC	--	--	--	18.7	26	36
Conductivity	uS/cm	--	--	--	48620	55230	100
Salinity	ppt	--	--	--	--	--	--
pH		7	8.4	25	8.13	8.38	99
Chlorophyll-a	ug/L	0	4	18	1.1	2.9	64
Turbidity	NTU	0	8	18	2	8	56
Dissolved Oxygen	mg/L	--	--	--	--	--	--
Dissolved Oxygen	%	85	100	58	88	95	83
Nitrate-N	ug/mL	--	--	--	--	--	--
Nitrite-N	ug/mL	--	--	--	--	--	--
NOx	ug/mL	0	10	100	2	4	100
Ammonia-N	ug/mL	0	10	100	6	13	99
Total N	ug/mL	0	300	96	0	250	100
Phosphate-P	ug/mL	0	6	24	5	12	14
Total P	ug/mL	0	25	14	18	32	94

The freshwater inflow pulse significantly changed the overall water chemistry of the Lake system: it resulted in a highly nutrient-enriched, low-saline and turbid water body that was clearly distinct from all other samples collected. Dendrogram and principal component analysis (Appendix 7) show that this shift in water quality, caused by catchment loads, remained clearly evident three days (at trip 2) after the inflow event. By contrast, there was little difference between the lake-wide water chemistry six days after the inflow event (trip 3) and subsequent sampling events (trips 4 to 12). This indicates relatively rapid recovery trajectory of water chemistry in the small coastal lagoon following a freshwater flushing event.

(Water Quality measurements at 0.5 m depth were averaged across all 7 sites for each time 1 to 12; dissimilarity measure is Euclidean Distance on square-root transformed and normalised data).

5.8 OBSERVATIONS ON SYSTEM RECOVERY

Immediately prior to the study commencing, a significant rain event occurred and the mouth was mechanically opened by the local council to prevent flooding. This remained open for the duration of this study. The rain event caused considerable freshwater flushing and dilution of the normally-saline system. Very little rain fell for the remainder of the study. The observations made in this study therefore depict the temporal return of the water quality indicators to a quasi-steady state.

Because these water quality indicators data are multivariate with respect to location, depth and time, the data are presented in two formats to illustrate different points. The temporal variation in the water quality indicators at each depth, for each monitoring site and the temporal variation in the vertical profile of the water quality indicators at each monitoring site are shown in Appendix 7.

Temperature

The large diurnal variation in ambient temperature caused significant variation in the measurements of water temperature of the upper water layers, depending on the time of day on which the sampling was undertaken. The temperature-depth profile at most sites were uniform, within 2°C, and did not vary significantly between trips. This is to be expected in winter, as the cooling and subsequent fall of the surface waters should ensure that all layers are well-mixed. However, as these sites undergo relatively little flushing and vertical mixing is inhibited due to a marked density layering caused by stratified salinity, strong temperature-depth profiles can develop. A slight variation in the temperature of the upper 1m of the water column was observed at sites 5 and 6, depending on the time of day that the measurements were made.

Salinity

Of particular significance is the time series of salinity as a function of time, which shows the rapid recovery of the system, at all sites, to a quasi-steady state, following the freshwater flooding event. The linear-first-order curve over the first few days, at all depths, indicates that the system is undergoing first order flushing with saline water, through tidal action. Salinity is an ideal indicator for this as it does not easily adsorb, deposit or transform chemically, so changes in concentration are therefore directly attributable to mixing. Note that the increasing salinity is not attributable to inflow from Kawana, as the salinity at sampling site 7 is equivalent to the surface salinity of Lake Currimundi and does not show the same temporal trajectory as the Kawana samples. Another consideration is that Lake Kawana is largely blocked off to tidal flushing with sea water.

pH

pH shows little variation across all sites and depths, although it does increase marginally at greater depths in the lower reaches of the Currimundi system. Immediately following the rain event, the pH in the lower reaches of the Currimundi system was low, which is to be expected after an influx of rain water, but quickly increased.

Chlorophyll

Chlorophyll is a pigment found in plants and is commonly employed as a proxy measure for phytoplankton (suspended microscopic algae) biomass. Plants require nutrient, sunlight and oxygen to grow. Immediately following the rain event, the system was highly turbid and chlorophyll levels were low. Of particular note, is the increase in chlorophyll levels at site 6, which is located at the blind end of a canal. At this location, particularly high levels of nitrogen-based nutrients were also observed, which may have been introduced via runoff from suburban gardens or other sources. The increase in chlorophyll corresponded to a decrease in dissolved oxygen at greater depths.

Turbidity

Turbidity also shows an exponential decline following the rain event, but is not directly attributable to flushing, as the particulate matter also undergoes deposition.

For this reason, the turbidity declined to steady state values at a significantly faster rate than salinity increased to steady state values.

Dissolved Oxygen

Dissolved oxygen values were generally good following the rain event, but showed a steady decline at greater depths at sites 5 and 6, which are blind ends of canals. Low rates of flushing (especially the deeper parts of the water column near the Lake bed) are the likely reason for the reduced oxygen levels in these blind canals.

Nutrient - Nitrogen

Immediately following the rain event, significantly elevated nutrient levels were recorded, especially nitrate. Ammonia levels slowly increased during the study, which is likely from total nitrogen indicates that a significant quantity of nitrogen is chemically bound to particulate matter and is therefore not readily available as nutrient, but may become available if conditions such as temperature or pH change.

Nutrient - Phosphorus

Immediately following the rain event, phosphorus levels were very high, but quickly decreased bacterial reduction of nitrate species.

5.9 QUASI-STEADY STATE CONDITIONS

As the Lake Currimundi is a highly dynamic system that is influenced by many variables, which include tidal action, storm runoff and Lake Kawana, it is unlikely that a steady equilibrium will ever be attained for any of the water quality indicators. For this reason, the results presented here represent quasi-steady state conditions.

The depth versus value profiles presented in the previous section were used to estimate the average "equilibrium" depth profiles for all water quality indicators at all sites. As the system underwent significant dynamic change in water quality indicators until trip 5, all quasi-steady-state profiles were estimated from the average of the profiles determined from trips 5 through 12, even though in some cases, as shown in the time-series plots, the system had not yet reached a definitive equilibrium.

For many of the water quality indicators, it is apparent that the depth profiles are similar at sites 1, 2 and 4 (strongly influenced by tidal action), site 3 (a creek), and sites 5 and 6 (blind ends of canals).

With the following exceptions, all average profiles were within the EPA water quality guidelines:

Chlorophyll: The average depth profile at site 6 is high, most likely due to the elevated nutrient levels and the lack of flushing.

Turbidity: This is elevated at depth at site 3, which is to be expected as this site is actually located in a small creek that carries a significant drainage flow down a narrow channel.

Dissolved Oxygen (%): DO falls below the recommended guideline of 85% in the deeper layers of sites 3, 5 and 6. As previously discussed, the low values are due to the microbial consumption of organic matter. The lack of vertical mixing and horizontal advection of oxygen-rich seawater via tidal action at sites 5 and 6 limits the transport of oxygen to the lower layers.

Nutrients (Nitrogen): Nutrient concentrations, which were only determined for the top layer, were significantly elevated above the EPA guidelines in all cases.

5.10 ANALYSIS OF SYSTEM MIXING

As described previously in this report, temporal variation in salinity measurements provide a means to estimate the degree and rate of mixing in a water body. The linear-first-order curve over the first few days, at all depths, is a clear indicator that the system in undergoing first order flushing with saline water. Salinity is an ideal indicator for this as it does not easily adsorb, deposit or transform chemically, so changes in concentration are therefore directly attributable to mixing between seawater and freshwater.

The temporal salinity data, for each depth at each site, were fitted using a Levenberg-Marquardt algorithm to the following linear-first-order function:

$$C_t = C_{\max}\left(1 - e^{-k(t+Dt)}\right)$$

where: C_t = salinity concentration at time t

C_{max} = maximum achievable concentration (steady-state concentration)

k = linear-first-order proportionality coefficient

Dt = arbitrary time offset

The parameters of importance are C_{max} and k. C_{max} represents the maximum concentration achievable for that system of data. k defines the rate at which the system changes to achieve C_{max}. This equation implies that the maximum level can never be reached, but the time it would take to reach some fraction of the maximum concentration (eg 95% and 99%) is readily calculated:

$$t_{95} = \frac{-\ln(0.05)}{k}$$

$$t_{99} = \frac{-\ln(0.01)}{k}$$

An example of a fitting run is provided in Figure 25 and the results from all fits are provided in Table 13. Note that site 7 is located in Lake Kawana and is unconnected to Currimundi, so has been excluded from this analysis.

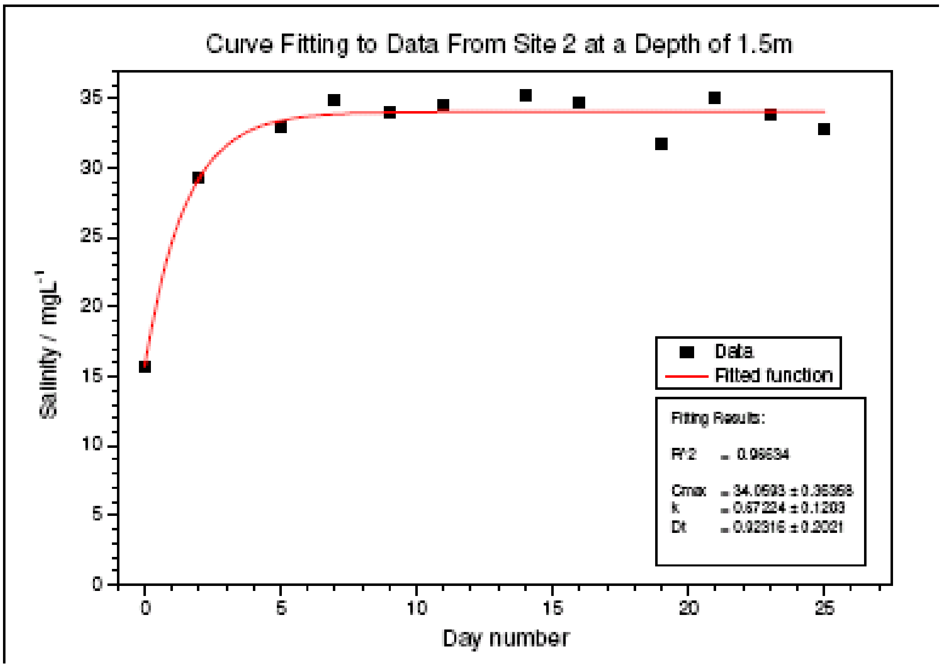


Figure 25: Example of a fitted curve to time-series salinity data.

Table 13: Results of curve fitting results to time-series data

Site	Depth / m	C_{max} / mgL^{-1}	k / day^{-1}	Time to 95% of Cmax / days	Time to 99% of Cmax / days
1	0.5	27.8	0.3827	7.8	12
1	1.0	31	0.5446	5.5	8.5
1	1.5	33.5	0.8619	3.5	5.3
1	2.0	35.3	1.5842	1.9	2.9
2	0.5	26.8	0.2459	12.2	18.7
2	1.0	30.7	0.2378	12.6	19.4
2	1.5	34.1	0.6722	4.5	6.9
2	2.0	35.3	9.0282	0.3	0.5
3	0.5	29.6	0.1222	24.5	37.7
3	1.0	30.2	0.446	6.7	10.3
3	1.5	34.5	0.6088	4.9	7.6
3	2.0	34.9	1.0126	3	4.5
4	0.5	26.6	0.2491	12	18.5
4	1.0	27.5	0.2552	11.7	18
4	1.5	31.4	0.2446	12.2	18.8
4	2.0	33.6	0.2815	10.6	16.4
4	2.5	34.9	0.4856	6.2	9.5
5	0.5	25.6	0.1449	20.7	31.8
5	1.0	27.4	0.1657	18.1	27.8
5	1.5	31.4	0.2042	14.7	22.5
5	2.0	34.2	0.2724	11	16.9
5	2.5	34.5	0.7203	4.2	6.4
5	3.0	35.1	0.2662	11.3	17.3
6	0.5	27.8	0.0643	46.6	71.6
6	1.0	27.1	0.1094	27.4	42.1
6	1.5	30.4	0.2019	14.8	22.8
6	2.0	34.2	0.2875	10.4	16
6	2.5	34.6	0.3827	7.8	12

Figure 26 and Figure 27 show that, for all locations in the lake system, equilibrium is reached faster at depth than nearer the surface. This is to be expected because the lower, more saline and dense layers would be less affected by a freshwater pulse than the surface waters. Continued freshwater inputs into the system, following the rainfall event, may also contribute to the slower recovery of the surface waters.

The rate of mixing at the surface is clearly dependent on the proximity to the mouth of the system, site 3 being an exception as it is a narrow tributary and is dissimilar to the other sites in this regard.

Of lesser significance in this analysis of system dynamics, is the maximum (or steady-state) concentration, as it is specific to salinity and does not apply to the other water quality indicators.

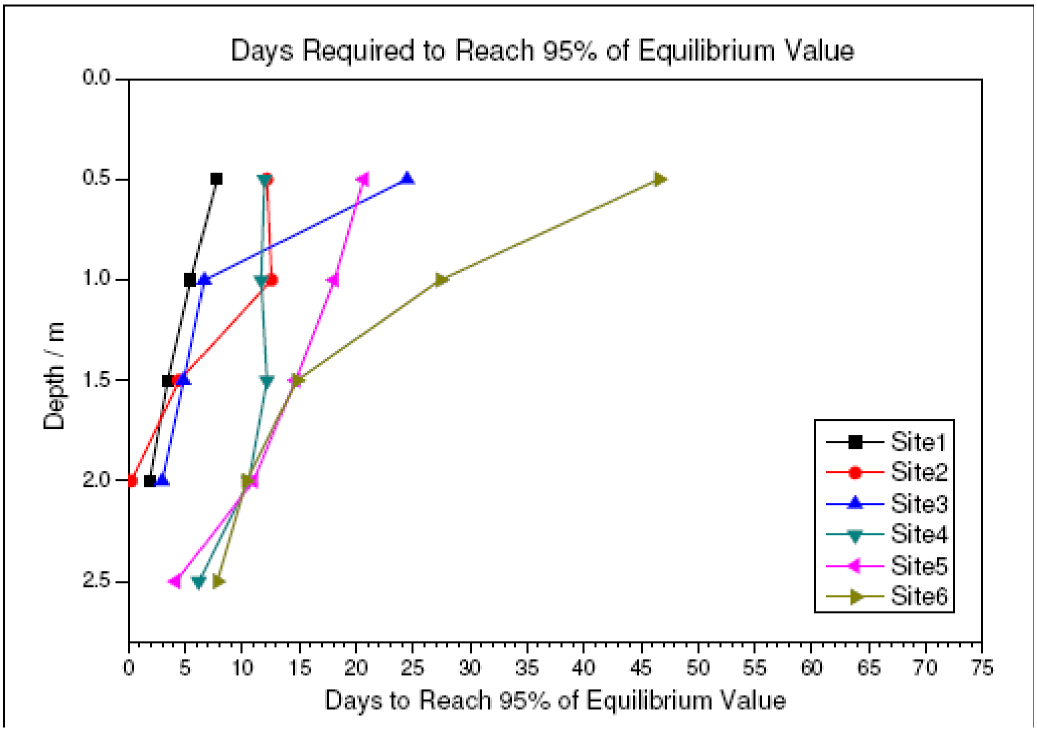


Figure 26: Time required to reach 95% of equilibrium values

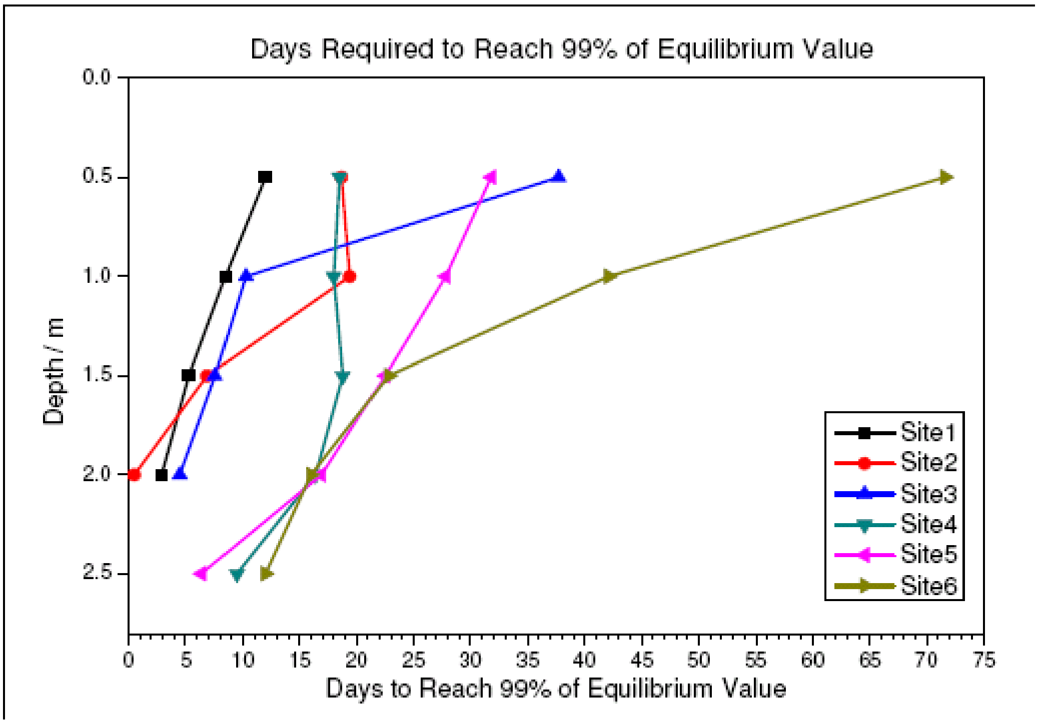


Figure 27: Time required to reach 99% of equilibrium values

Figure 28 indicates that the equilibrium salinity depth profiles at sites 1, 2 and 3 are similar, and equilibrium salinity depth profiles at sites 4, 5 and 6 are similar. These grouping may be based on the degree of tidal influence at these sites. The proximity of sites 1, 2 and 3 to the ocean result in the elevated salinities at lesser depth, while sites 4, 5 and 6 only show ocean-level salinity in the deepest layers. This again is evidence that the surface layers in the canals are more susceptible to freshwater inputs than those located closer to the mouth of the system.

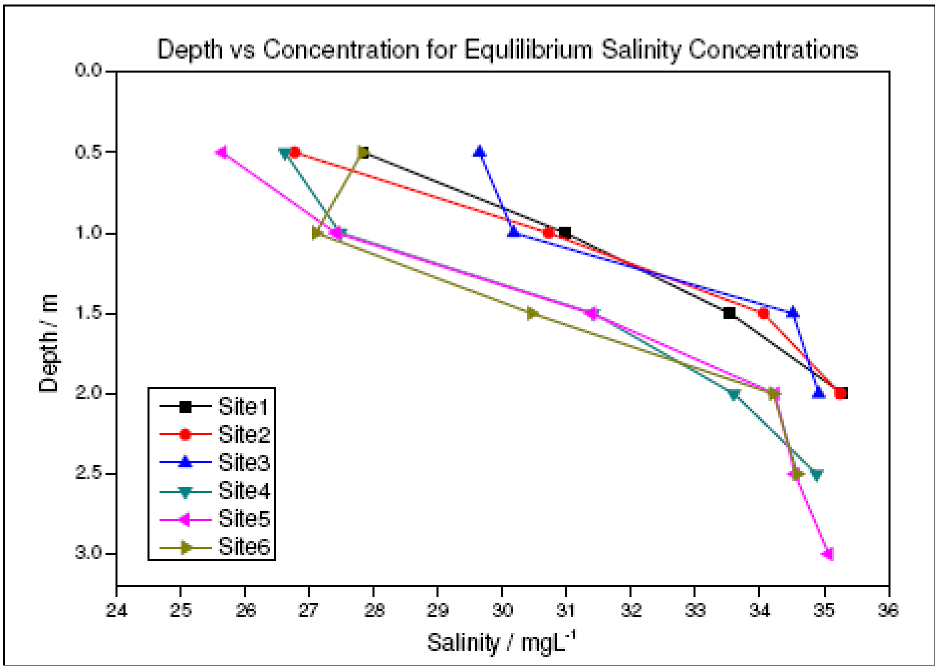


Figure 28: Maximum (equilibrium) salinity at monitoring sites as a function of depth.

5.11 SUMMARY

To evaluate the spatial variability of water quality indicators throughout the lake system.

The water quality indicators for the top 1m of the water body were generally comparable at all sites during the study period. Of particular note, nitrate concentrations, and subsequently chlorophyll concentrations were elevated at sampling site 6.

The vertical profile of water quality indicators, salinity in particular, was most pronounced at sampling sites 4, 5 and 6, where high concentrations were observed at the bottom of the water column.

To evaluate the changes that occur in the lake system in response to a pulsed freshwater inflow flood event.

Immediately after the freshwater flood event, turbidity and nutrient concentrations were significantly elevated and salinity was depressed. While the turbidity and phosphorus nutrients decreased rapidly, nitrogen nutrients did not. Chlorophyll and ammonia increased over the subsequent three weeks. Salinity readings slowly increased at different rates, depending on location and depth, and were used to estimate rate of mixing by tidal action.

To evaluate the rate at which the system returns to average conditions (stabilizes) after a large rainfall event.

The rate of mixing by tidal action varies with respect to location and depth. All deeper parts of the system are fully mixed and equilibrated after approximately 8 days, even at the blind ends of the canals, but surface layers may take up to 60 days (especially at the blind ends of the canals).

To evaluate the spatial variability and depth-profiles of water quality indicators, after the system has stabilized.

Approximate steady-state concentrations and values have been estimated, as a function of location and depth, based on the groupings of data collected after two weeks of no rain. With the exception of nitrogen-based nutrients and some indicators in the deeper waters, these concentration profiles are all within the general EPA water quality guidelines.

CHAPTER 6 – LAKE CURRIMUNDI WATER QUALITY DYNAMICS

Advanced statistical methods using generalised additive models (GAMs) are used here to explore water quality datasets for functional relationships between variables of interest (nutrients, faecal coliform count, chlorophyll-*a*) and a suite of environmental and metrical (year, month) variables. This nonparametric approach to regression allows the data to 'speak for itself' and therefore makes no *a prior* assumptions regarding the shape of the function between selected covariates.

Much of the output of the work presented here can be considered as representing "conceptual" models of various aspects of lake dynamics, in that the GAM modelling is most useful in identifying broad relationships between various parameters.

The GAM assessment was carried out on two water quality datasets for Lake Currimundi (i) Caloundra City Council's (CCC) monitoring program, 2001 – 2006; and (ii) a short-term intensive monitoring period carried out in June, 2008. This section separately outlines these two assessments.

6.1 Modelling Environment

The GAM assessment and associated diagnostic tests were conducted in the statistical software R (Ihaka and Gentleman 1996) using the *mgcv* package (Wood 2008). Model diagnostics were carried out for each model run to ensure that the model assumptions (normality and constant variance) and full convergence were attained. All missing data, indicated by 'NA' in the dataset, were specified to be ignored by the model.

Model selection was carried out by iteratively running the GAM and dropping parameters that were not significant in the model ($p = 0.05$) (Wood 2008). The preferred model was then selected by comparing the generalised cross validation (GCV) score for each model and reviewing the p-values (Wood 2008).

6.2 CCC Monitoring Data, 2001 – 2006

Water quality data for Lake Currimundi has been systematically measured by the CCC since 2001 and therefore a GAM assessment of this dataset enables broad long-term patterns to be identified.

The focus of this assessment was to (i) evaluate the important factors (effects) and trends associated with the concentration of dissolved inorganic nitrogen (DIN) and faecal coliform counts (coliform) in the lake and (ii) identify the antecedent conditions leading to elevated DIN, where DIN is the sum of measured concentrations of ammonia (NH_3) and oxides of nitrogen (NO_3 + NO_2), and coliforms. Improved understanding of these will assist in fine-tuning management protocols (LEROMP) for the lake.

6.3 Dissolved Inorganic Nitrogen

6.3.1 Initial Data Evaluation

Basic plots were constructed for DIN against the metrical-phys-chem parameters (refer Appendix 6). Diagnostic tests indicated that model assumptions of normality, constant variance and independence were achieved during trendline fitting. Note that total phosphorus (TP) and dissolved reactive phosphorus were not included in this analysis even though this data is available because these are potentially entering the system with the DIN. A comparative plot between DIN and TP supports this supposition.

It is hypothesised that there is a strong association between catchment rainfall/runoff and the water quality dynamics of Lake Currimundi. Cumulative monthly rainfalls were used as a predictor variable instead of daily rainfall amounts because i.) cumulative rainfall is more likely to account for lag-time between rainfall occurring and nutrient loading, and ii.) only month and year of sampling were available (i.e. no specific monitoring dates were available). A one-month lagged cumulative rainfall variable was also included (e.g. the cumulative rainfall for June 2004 is matched with DIN concentrations for July 2004) because of the uncertainty regarding when the water quality sampling occurred during each month i.e. if sampling occurred at the beginning of each month then the cumulative rainfall for the previous month would more likely have a functional relationship with the water quality data.

Negative relationships were observed between DIN and temperature, conductivity, DO, TSS and lagged cumulative (1 month) rainfall while positive relationships were observed with turbidity and total nitrogen (TN). There was no significant trend for year or month although the latter indicates a possibly cyclical trend.

Finally, several of the parameters (Figure 29) appear correlated; preliminary tests indicated that the most prominent is the positive relationship between conductivity and TSS. It is concluded that conductivity or TSS should not be used simultaneously in the GAM assessment because they are so closely related.

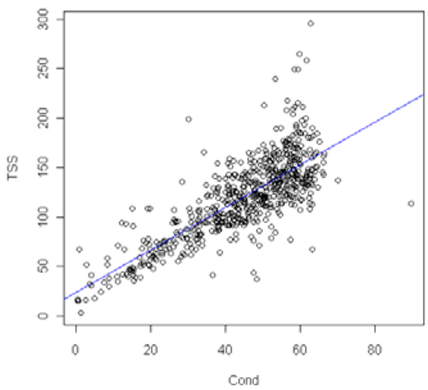


Figure 29: Comparison of TSS versus conductivity (R^2 = 0.61)

6.3.2 GAM Development

The initial evaluation of the data indicated that there were patterns of interest between DIN and most of the parameters trialled. Consequently, the initial GAM was trialled with all of the significant parameters highlighted in the initial data evaluation. The exception was TSS, which was omitted because of the strong correlation that it has with conductivity (Figure 122). Month was included in the initial model because of a possible cyclical relationship with DIN.

A factor term (*Kawana*) was also included in the initial GAM to represent the initiation of water transfer from Kawana Lake to Lake Currimundi from January 2005 (0 = no transfer, 1 = transfer occurring). This management process has been linked to controlling the water quality dynamics in the lake and therefore its effect, if any, on DIN needs to be assessed.

Preliminary modelling highlighted a strong effect on the regression analysis due to a single DIN concentration (3.128 mg/l) for March 2003 at the Baroona Canal that was an order of magnitude higher than all other DIN concentrations in the dataset. Such an outlier has the potential to bias the regression analysis and therefore this outlier was subsequently removed from the model.

Two outliers were also identified for water temperature:

- 50.5 ºC, April 2006, Baroona Canal
- 57.6 ºC, November 2005, Lakeside Retirement Village

These temperature levels were removed from the data set because of their biasing effect.

Finally, a Gaussian family object (Gamma) with a logarithmic link function (Wood 2008) was specified for the distribution in model fitting.

6.3.3 Model Selection

Model diagnostics were carried out on the selected model to ensure model assumptions of normality and constant variance were validated (see Appendix 6).

The preferred model is the initial model containing parameters *Year*, *Month*, *lagged cumulative rainfall, cumulative rainfall, conductivity* and *DO*. The associate smoothing functions are presented in Figure 124. The first two plots (*Year* and *Month*) show the scale of effect and trend for each parameter using the mean and 95% confidence interval (two standard errors). The x-axis represents the predictor variable (*Year*, *Month*) and the y-axis represents the relative effect of the covariate[2].

The bottom two plots of Figure 124 each show two smooth functions, each of two predictors (i. *lagged cumulative rainfall* and *cumulative rainfall*; ii. *conductivity* and *DO*). Solid lines indicate the estimate of the smooth while the dashed/dotted lines indicate the standard errors.

Summary statistics of the final model indicated that all coefficients were significant ($p < 0.05$).

Effect of sampling year on DIN

There is a strong annual component in the observed DIN data, most notably around 2002 and 2005. The strongest effect occurred at 2002, whereby there appears to be an increase in DIN, which then decreases after 2002. The reason for this is not known but might be climate-driven as 2002 approximately coincides with the transfer from a La Niña to El Niño climate cycle.

The ‘peak’ and subsequent decline in the yearly effect (i.e. a general long-term decrease in DIN) from 2005 may reflect specific management outcomes such as opening the lake mouth and the commencement of regular water transferred from Lake Kawana in early 2005. The impact of this management action might be the reason for the decline in annual effect on DIN due to subsequent increased flushing

[2] Scale of covariate effect centered about the origin such that the sum of the effects = zero (Wood 2008)

and circulation of the Lake. However, specific testing for the effect of water transfer from Kawana (as a factor) did not highlight this as significant.

Effect of sampling month on DIN

A pronounced seasonal (monthly) effect is also evident for DIN. There is an indication that this seasonal effect is stronger (i.e. increased DIN concentrations) during June-August. This might reflect decreased primary production (phytoplankton), which reduces uptake (by the phytoplankton) allowing the nutrients to remain dissolved in the water column. Potential seasonal factors such as wind regimes or even tidal attenuation (flushing) might also be important in governing the seasonal trends in DIN. Finally, the seasonal effect may also be influenced by the cumulative rainfall variables, which will also have a seasonal component. The model was trialled without 'Month" but was found to weaken the model.

Effect of conductivity and DO on DIN

Increased conductivity and dissolved oxygen (DO) concentration are indicators of increased flushing of the lake. Therefore, the negative relationship between these two variables and DIN suggests that increased oceanic exchange and flushing decreases DIN. This is not an unexpected relationship given that oceanic DIN concentrations will be much lower than in the lake.

Note that *DO* and *conductivity* are potentially cross-correlated because they are both indicators of oceanic exchange. However, regression models trialled with only *DO* or *conductivity* on its own were poorer than the best-fit model selected here. Furthermore, the model was found to be improved by grouping *DO* and *conductivity* together rather than modelling them as separate variables - this is why these two variables are shown as a contour plot in Figure 30.

Effect of cumulative rainfall on DIN

The relationship between cumulative rainfall and DIN is not overtly clear based on the contour plot (Figure 30, third panel). However, general interpretation of the contours indicates that there is a positive effect (increasing DIN) at monthly cumulative rainfalls below 100mm. Above this threshold, the effect is generally negative (decreasing DIN).

The positive effect at <100mm indicates that catchment loading is significant in increasing DIN concentrations. Again, this relationship is not unexpected and supports the hypothesis that catchment rainfall/runoff is a significant contributor to DIN in the lake.

The negative effect at >100mm suggests that during periods of greater rainfall the nutrient load is sufficient to trigger accelerated phytoplankton growth, which then depletes the nutrient pool. This influence is supported by the GAM assessment of an intensive water quality monitoring dataset detailed in the following section. It is also possible that the rainfall itself has a dilution effect, perhaps diluting the loading and/or increasing the oceanic flushing through breaching the sand berm at the mouth.

As with conductivity and DO, the regression model was found to be improved by grouping the two rainfall variables together rather than modelling them as separate variables.

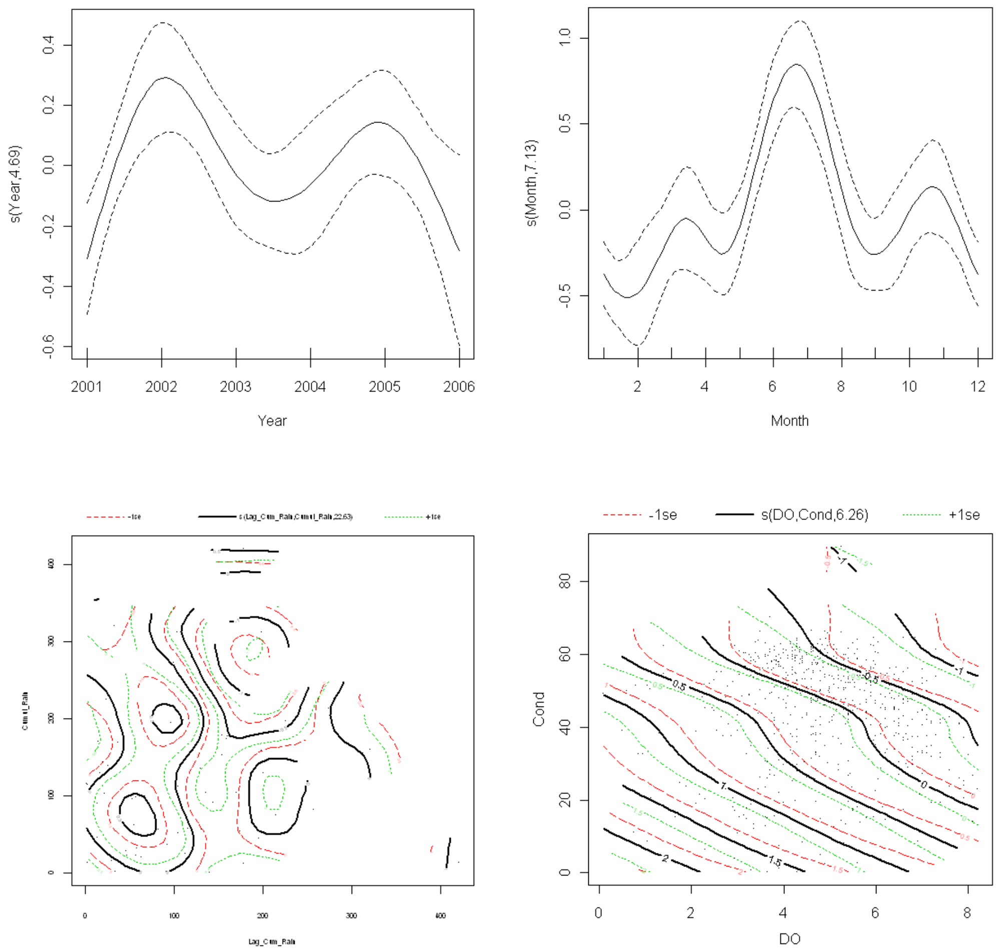


Figure 30: The fitted GAM with DIN as the response variable. The top two panels show the smoothed plots for Year and Month respectively. The bottom two panels are the smooth isotropic functions for *cumulative monthly rainfall* and *monthly rainfall* (third panel) and *conductivity* and *dissolved oxygen* (fourth panel) and where individual data points are shown as black dots (·).

6.4 Faecal Coliform Count

6.4.1 Initial Data Evaluation

Basic plots were constructed for faecal coliform counts (coliform) against the metrical-phys-chem parameters and the rainfall data (Appendix 6) in a similar manner carried out for DIN (see previous section). Diagnostic tests indicated that linear regression modelling assumptions of normality, constant variance and independence were achieved during trendline fitting.

Negative relationships were observed between coliform and conductivity, DO, TSS while positive relationships were observed between faecal count and cumulative rainfall, turbidity, DIN, BOD, and to a lesser extent for Year. There was no significant trend for temperature or month, however there is indication that the latter (i.e. month) has a cyclical or nonlinear relationship with faecal coliform count.

There is a distinct group of variables that indicate a positive effect on faecal coliform count (Year, turbidity, DIN, BOD and cumulative rainfall). These parameters are predominantly linked with catchment-based processes i.e. catchment runoff. Conversely, there is another distinct group of variables that have a negative effect on faecal coliform count (conductivity, DO and TSS), which may indicate a more oceanic effect, especially DO and TSS.

6.4.2 GAM Development

The initial construction of the GAM is guided by the preliminary data evaluation of the previous section. All parameters that had a significant linear trend were included in the initial model. The exceptions were TSS, which was omitted because of the strong correlation that it has with conductivity, and BOD, which was omitted because of insufficient data.

Month was also added as a parameter despite not indicating a significant linear trend because this parameter displays a possible cyclical trend rather than a linear one.

Finally, the factor variable (Kawana) was included to evaluate the potential influence of water discharged from Lake Kawana since 2005 on coliform count.

A *quasi* family was used as diagnostics indicated that it was better than other responses (e.g. Gamma) at achieving the assumptions of normality, constant variance and independence. Model assumptions were improved by using log-transformations for Faecal count, DIN and DO.

6.4.2.1 Model Selection and Description

Model diagnostics were carried out on the selected model to ensure model assumptions of normality and constant variance were validated (refer Appendix 8). The preferred model is the initial model containing 8 parameters. The estimates of the model are summarised in Figure 31. The clearest effects are year (annual effect), conductivity and Kawana, the latter indicating the efficacy of inputting Lake Kawana water into Lake Currimundi.

Effect of year on coliform

There is a clear positive and linear annual (Year) effect on coliform (Figure 31a) indicating that there has been a long-term increase. However, the annual variable does not take into account the effect of introducing Lake Kawana water into Lake Currimundi that has occurred since early 2005.

Effect of Lake Kawana inflow on coliform

The effect of introducing Lake Kawana inflow to Lake Currimundi in 2005 is significant and negative i.e. has reduced faecal coliform counts (Figure 31h). To further test the role of Kawana input flow, the factor Kawana was removed from the GAM and the model re-run (Figure 32). The left-hand panel shows the annual effect of Kawana in the model and the right-hand panel shows the annual effect when the factor Kawana has been removed. When Kawana inflow is not modelled explicitly, the effect of this inflow still appears to be captured by the sudden decrease observed in the annual effect at 2005.

Effect of conductivity on coliform

There is a strong negative effect of conductivity on coliform at conductivities above ca. 50 mS cm^{-1} (Figure 31g). Below 20 ms cm^{-1}, this effect is slight while between 20 - 50 ms cm^{-1}, this effect is effectively zero. This indicates oceanic flushing of the faecal coliform is effective, but probably only in areas that have significant oceanic water ingress i.e. closer to the entrance.

Effect of dissolved oxygen concentration on coliform

There is a negative effect of DO (log_{10} transformed) at concentrations above 1 mg l^{-1} (Figure 31f). Increasing DO is probably an indicator of mixing as there is a similar trend for conductivity (Figure 127g) and therefore this effect reaffirms that there is some oceanic flushing of the coliform.

Effect of monthly cumulative rainfall on coliform

The serpentine rainfall effect (Figure 31c), which might indicate an ‘overfitted’ model or may reflect the coarseness of this parameter. However, general trends are still discernible. Below ca. 25mm cumulative rainfall, there is a negative effect while above 25mm there is a general positive effect. This indicates a cumulative rainfall threshold (25mm) when catchment runoff initiates loading of faecal coliforms into the system. However, it is re-iterated that this interpretation needs to be kept in the context of the coarseness of this parameter that arises due to the distance between the rainfall monitoring station (Maroochy aerodrome) and Lake Currimundi, along with the uncertainty in monitoring dates.

Effect of season (Month) on coliform

The seasonal effect (month of sampling) (Figure 31b) indicates an overfitted model, potentially because Month and Cumulative rainfall may be covariates. However, the increased positive effect on coliform from January to February and the conversely decreased effect from February to April might reflect the influences of rainfall patterns and Spring tides respectively.

Effect of turbidity on faecal coliform

Below ca. 10 NTU, there is a positive linear effect of turbidity on coliform that might reflect coliform entering the system with organic matter. Above 10 NTU, there is no significant effect as indicated by the large confidence bands (Figure 31d).

Effect of dissolved inorganic nitrogen on coliform

DIN (log_{10} transformed) has a positive effect on coliform counts, most likely because both parameters are entering the system together.

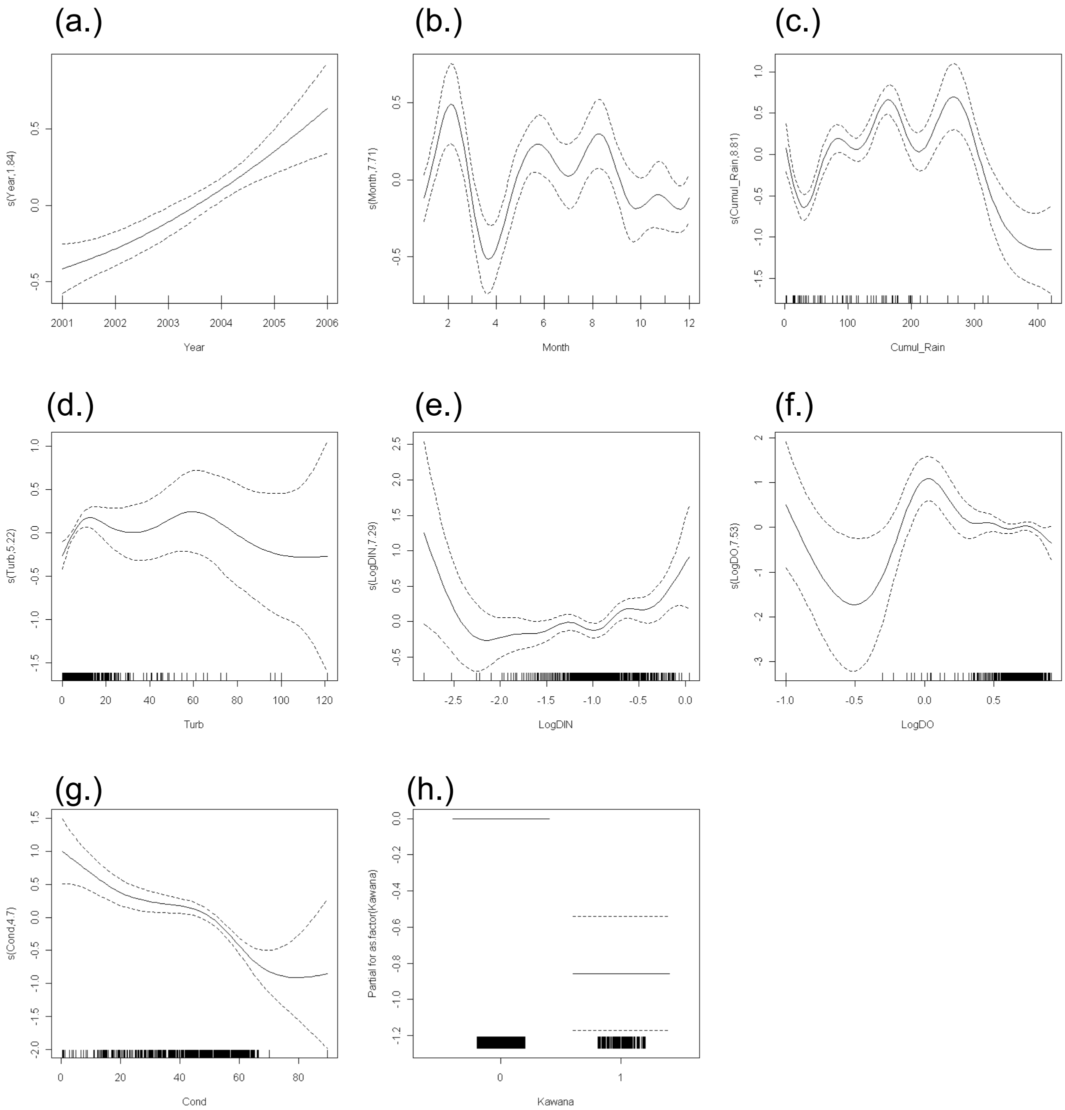


Figure 31: Estimated model terms for the selected faecal coliform count model (a) annual effect (Year); (b) Month; (c) monthly cumulative rainfall; (d) turbidity; (e) $\log_{10}$ transformed DIN; (f) $\log_{10}$ transformed DO; (g) conductivity; (h) Lake Kawana inflow.

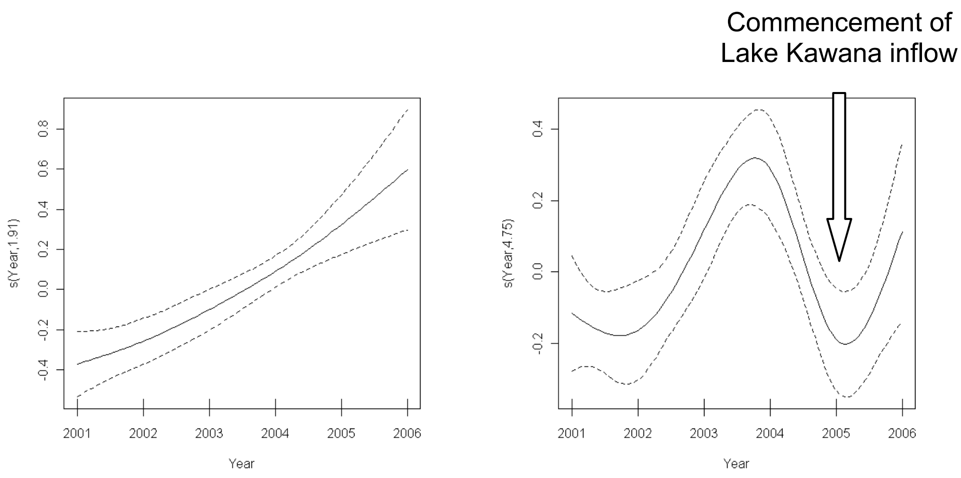


Figure 32. The annual (year) effect on coliform counts in Lake Currimundi with (left-hand panel) and without (right-hand panel) Kawana inflow being explicitly included in the GAM.

6.4.3 GAM assessment of intensive water quality monitoring data, June 2008

An intensive water quality monitoring program (seven sites on 12 days) was undertaken in Lake Currimundi in June 2008 by Sunshine Coast University (Wiegand and Schlacher 2008). A suite of water quality parameters were measured during this program including chlorophyll-*a*, a proxy measure for phytoplankton biomass and an important indicator of ecosystem health. Previous water quality monitoring in the Lake have not included chlorophyll-*a* and therefore this dataset provides an excellent opportunity to explore the functional relationships associated with this important parameter.

The context of this water quality monitoring program is that it occurred shortly after the entrance to the Lake had been dredged and therefore incorporates tidal flushing. Furthermore, the water quality monitoring undertaken by SCU commenced one day after a significant rainfall event in the catchment (160mm at Maroochydore Aerodrome) allowing its effect on chlorophyll-*a* to be included in the assessment.

The overall aim of this assessment is to evaluate the spatial (vertical and horizontal) and temporal functional relationships of chlorophyll-*a* in Lake Currimundi within the context of a recently opened entrance and a recent rainfall event. The objectives are to:

- determine whether there is a significant spatial (horizontal and vertical) pattern in the chlorophyll-*a* measurements observed
- determine the extent of the effect that the significant rainfall event that occurred 1-2 June 2008 had on the chlorophyll-*a* dynamics
- determine the extent of the effect of tidal flushing on the chlorophyll-*a* dynamics
- identify antecedent conditions for increased chlorophyll-*a* conditions
- to comment on the combined findings of the GAM assessments undertaken on the SCU and CCC water quality data

6.4.3.1 Initial Data Evaluation

Basic plots were constructed for chlorophyll-*a* concentration against the metrical-phys-chem parameters (Figure 33). Where trendlines are shown, significant ($p < 0.05$) linear trends could be fitted. Diagnostic tests indicated that model assumptions of normality, constant variance and independence were achieved during trendline fitting.

The ‘days since rainfall’ variable is a measure of the time period between the large rainfall event that occurred on 2/06/2008 and the sampling. The rationale is that this period of time will have a strong influence on the chlorophyll-*a* concentrations that were measured due to nutrient loading, nutrient uptake and oceanic mixing.

Negative relationships between chlorophyll-*a* and turbidity (NTU) and DO. Positive relationships between chlorophyll-*a* and monitoring location (Site), time between the rainfall event on 2/06/08 and the monitoring (time_since_rain), temperature (Temp) and dissolved inorganic nitrogen (DIN). There was no significant trend for depth of sampling (Depth), salinity or PO_4.

6.4.4 GAM Development

The initial construction of the GAM is guided by the preliminary data evaluation of the previous section. All parameters that had a significant linear trend were included in the initial model. The exception was *Site*, which was replaced by the georeference coordinate system (i.e. latitude, longitude) for each monitoring site.

Nutrient data was not included in this assessment because it was only measured at a depth of 0.5 m whereas chlorophyll-*a* was measured at multiple depths.

There were 59 chlorophyll-*a* measurements of 0 μg l^{-1}. These recordings were ignored in the GAM assessment because their presence caused the modelling assumption of normality to be compromised.

6.4.4.1 Model Selection and Description

A Gamma family has been used as diagnostics (refer Appendix 6) indicate that it achieved the assumptions of normality, constant variance and independence.

The preferred model contains the covariates of longitude coordinates of the sampling site (Long), the period between the rainfall event on 2/06/2008 and the sampling (*time_since_rain*), salinity, water temperature (*Temp*), turbidity (*Turb*) and sampling depth (*Depth*). The estimates of the model are summarised in Figure 33. The strongest effects are *time_since_rain* (Figure 33b) and *salinity* (Figure 33c) and to a lesser extent, *Temp* (Figure 131d) and *longitude* (Figure 33a). All variables are significant ($p<0.05$) except for *Depth*.

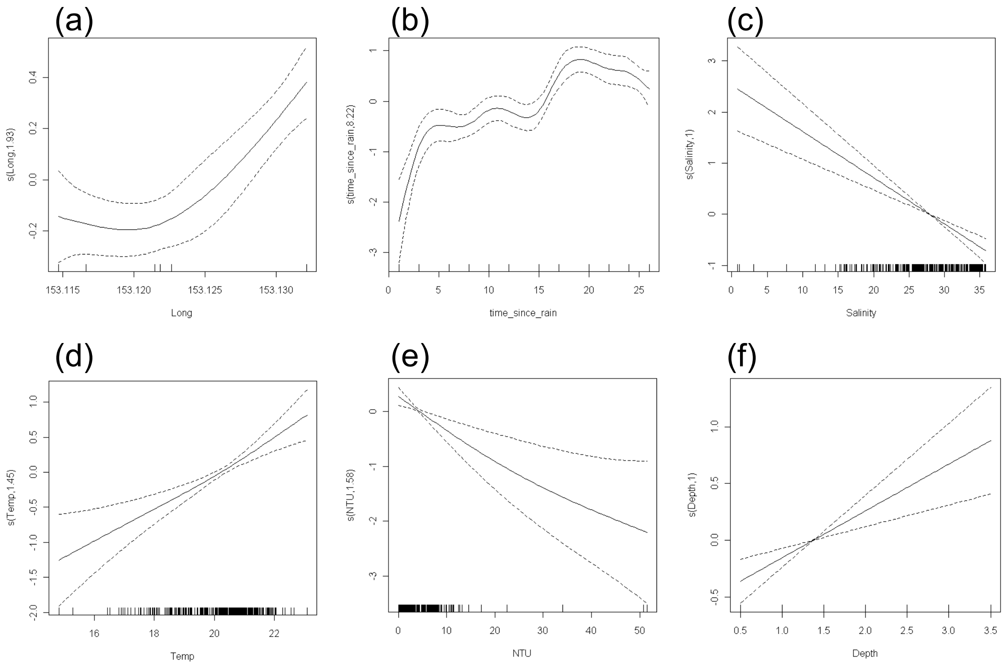


Figure 33. Estimated model terms for the selected model for chlorophyll-*a* (a) Longitude coordinate of monitoring site; (b) number of days between rainfall event on 02/06/2008 and sampling; (c) salinity; (d) water temperature; (e) turbidity; (f) depth of water sampling.

Effect of the duration between rainfall event (2/06/08) and sampling on chlorophyll-*a*

This variable has the strongest effect on chlorophyll-*a*. Figure 33b shows that for a period of five days after the large rainfall event, there was a strong positive effect on chlorophyll-*a* in Lake Currimundi. This is followed by a period of relative stability between 5 – 15 days before another strong positive increase until day 18, after which there is slight decline.

The strong positive effect during days 1 – 5 most likely reflects a period of rapid phytoplankton growth facilitated by the input of nutrients from the catchment. In turn the abrupt cessation after day 5 might indicate that the introduced nutrients have been removed, most likely as a result of the phytoplankton consuming the nutrients. Oceanic flushing may also be contributing to the removal of nutrients.

The secondary effect between 15-18 days could reflect the nutrients recycling back into the water column caused by phytoplankton respiration and mortality. These processes release nutrients back into the water column where they are available for renewed phytoplankton growth. Alternatively, this might highlight a new source of nutrients discharged into the system.

A smaller rainfall event (ca. 20mm) was recorded at Maroochy Aerodrome on 22/06/08. However, this rainfall was 20 days after the large rainfall event recorded on 2/06/08 and therefore falls outside of the secondary effect seen between days 15 – 18. Notwithstanding the distance between the meteorological station and the Lake, this observation supports the GAM assessment carried out for the existing CCC water quality data, which indicated a positive effect on dissolved inorganic nitrogen

(DIN) concentrations for cumulative rainfalls up to ca. 100mm, whereas above this threshold there was a negative effect. This pattern indicates that a 'large' rainfall is required to initiate phytoplankton growth, after which the nutrient pool is depleted.

Effect of water temperature on chlorophyll-*a*
Water temperature is a significant effect of chlorophyll-*a*, having a linear positive effect (Figure 33d). Water temperature is known to be a major factor in phytoplankton growth, with increased growth typically observed during warmer conditions and this appears to be reflected here.

Effect of easting Coordinate (Long) on chlorophyll-*a*
The model highlights an apparent increasing effect of the easting coordinate on chlorophyll-*a* concentrations indicating that sites located further from the coastline have higher chlorophyll-*a* concentrations than those closer (Figure 33a). However, this effect is most pronounced at the most western site (Site 3) with the remaining 6 sites showing little difference.

Effect of turbidity on chlorophyll-*a*
There is a negative effect of turbidity on chlorophyll-*a* (Figure 33e). Turbidity is typically a limiter of phytoplankton growth because it restricts the solar irradiance received by the phytoplankton.

Effect of salinity on chlorophyll-*a*
This variable indicates the influence of oceanic flushing on chlorophyll-*a* concentrations (Figure 33c). The GAM plot shows that there is a linear and negative effect of salinity, which indicates that oceanic flushing is significant in reducing chlorophyll-a concentrations. However, the GAM plot indicates that this is not a dominant variable.

Effect of sampling depth on chlorophyll-*a*
There is a positive effect of depth on phytoplankton, which is opposite to expected (Figure 33f). However, the GAM plot for this variable indicates that this is not a dominant variable.

6.5 OVERALL CONCLUSIONS

The generalised additive modelling (GAM) undertaken here on two datasets for Lake Currimundi has highlighted some potentially important temporal and environmental characteristics:

DIN:

1. The annual trend in DIN indicates potential combine effect of climate signature (El Nino/La Nina cycle) and the introduction of inflow from Lake Kawana in 2005.
2. There is a strong winter effect on DIN that probably reflects decreased primary production (photosynthesis) and therefore decreased nutrient uptake.
3. Decreasing DIN with increasing DO and conductivity indicating some level of effective oceanic flushing
4. Monthly cumulative rainfall levels below ca. 100mm appear to lead to increased DIN, most likely due to catchment runoff