5. Monthly cumulative rainfall levels above ca. 100mm appear to lead to decreased DIN, most likely to trigger of primary production leading to nutrient depletion and/or dilution effect.

Faecal coliform count:

1. There is strong indication that the introduction of the Lake Kawana inflow into Lake Currimundi in 2005 has been effective in decreasing coliform counts despite there being an increasing annual trend in coliform.
2. Oceanic flushing occurring, but probably mainly for sites nearer the entrance (as indicated by conductivity)

Chlorophyll-*a*:

1. Chlorophyll-*a* concentrations in Lake Kawana appear to be significantly influenced by large rainfall events. The large event on 2nd June 2008 resulted in a rapid increase in chlorophyll-*a* for the following five days, followed by a lull for the next 10 days and a secondary increase in chlorophyll-*a* for the subsequent three days. The secondary peak in chlorophyll-*a* is thought to result from nutrient cycling.
2. Smaller rainfall events appear to have minimal influence on chlorophyll-*a*, probably due to insufficient nutrients to trigger primary production.
3. There is evidence that there is a site-dependency on the chlorophyll-*a*, with higher chlorophyll-*a* observed further from the entrance. However, this spatial effect is strongly biased by Site 3.

CHAPTER 7 – LAKE HYDRODYNAMICS

7.1 INTRODUCTION

The management of Lake Currimundi requires detailed understanding of the physical processes which are occurring under the current entrance configuration. Prior to the connection to Lake Kawana, the lake was considered to be an Intermittently Closed and Open lake and Lagoon (ICOLL), and as such the system responded primarily to increase freshwater inflow resulting in a build-up of water level and subsequent entrance breakthrough. Similarly a major coastal storm could cause a breakthrough of the entrance followed by penetration of storm surge and then a return to lower water levels and subsequent closure of the entrance by natural wave-induced sand movement into the entrance.

With the current configuration, the entrance remains open for the majority of the time under the influence of the flow-through from Lake Kawana. This also results in more normal tidal flow during periods following the artificial opening of the entrance In recent years, the entrance has been artificially closed for biting midge control, and then artificially opened following a period of a few weeks depending on the midge control strategy.

From the analysis of water quality, bank erosion and biting midge control issues it is clear that there is a need to understand the magnitude of currents impacting on the waterway, the range of water levels in the Lake in response to entrance closure and freshwater input; the time of recovery following an entrance opening back to a near closed state; and the impact on tidal flows of the connections with Lake Kawana.

In order to gain some understanding of the physical processes a number of field exercises have been carried out, and a hydrodynamic model developed for the Lake under tidal forcing.

In the following sections insights into the physical characteristics of the lake will be presented based on a detailed description of the fieldwork given in Appendices 9 and 10; the capability of the hydrodynamics model will be demonstrated; and recommendations will be given for the use of the model and the establishment of physical parameter monitoring programs.

7.1 RESULTS FROM THE PRELIMINARY FIELD EXERCISES

7.1.1 July 2007 Exercise

Preliminary testing began on the lake in late July 2007 prior to the dune re-profiling work and construction of the wading pool at the entrance of Lake Currimundi. This presented an opportunity to establish some baseline data to assist in the preparation for a more comprehensive exercise and to assist in the design of a long-term monitoring program.

A hydrographic survey was carried out over a two-day period, 26 and 27 July 2007, using a SonTek Argonaut velocity profiler and other various equipment (Appendix 9). Five sites (see Figure 34) along the lake were analysed for water level and velocity. The GPS location of each site was noted as well as the water temperature, depth and water flow direction.

Figure 34: Map of Lake Currimundi with field trip no.1 site locations (Source: Google Earth)

The main finding of this exercise was that the velocity of tidal flow is relatively low throughout the lake with typical values of 0.05 – 0.1 m/s (see Figure 35). Tidal range was also small at around 0.2 m. There was a considerable phase lag (around 4 hours) between the increase in velocity on the outgoing tide at the bridge and at the weir location. Presumably the higher velocity at the weir is a function of the onset of controlled flow over the weir on the outgoing tide. These findings are consistent with a highly constrained entrance.

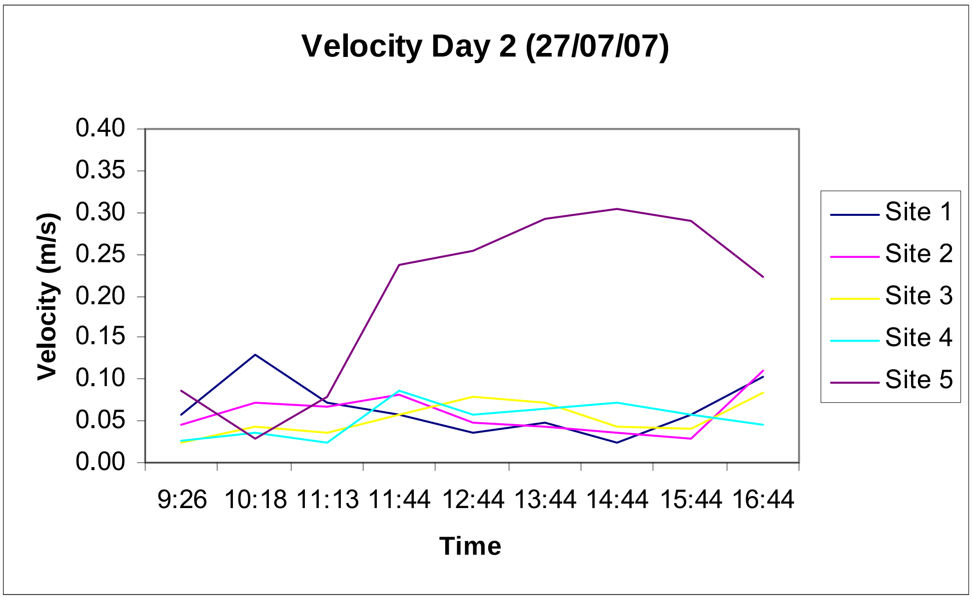

Figure 35: Velocity readings for Lake Currimundi on 27/07/07

7.1.2 October 2007 Exercise

Fieldwork was completed on the Lake from the 24th October to the 29th October 2007, in conjunction with the final stages of the entrance closure to control midge. In particular, the purpose of the exercise was to monitor the changes during and immediately after the opening on the 26th October 2007. The same monitoring sites were used as in July, but with additional water quality measurements taken in relation to temperature, pH, dissolved oxygen and conductivity as part of a preliminary assessment of requirements for a major water quality monitoring planned for 2008. Velocity data were again measured, this time at different locations mainly near the entrance, as well as measurements of tidal range.

The main findings from this fieldwork are as follows.

- The lake maintains a strong tidal signal for at least 3 days following the entrance opening (see Figure 36).
- There is a strong tidal asymmetry typical of estuaries with the flood tide velocity being greater in magnitude than the ebb, but for a shorter period. This asymmetry is the main driver for sand to quickly infill the entrance and cause it to close.
- Following the lake opening, maximum water level is actually higher than that during the closure
- The flow reversals are in phase (or nearly) with the high and low water marks. This suggests that the lake (including the connection to Lake Kawana) is not influenced by tide attenuation due to bottom friction (except most likely for the initial friction loss at the entrance). This means that only one water level monitoring site will be required to describe the dynamics of the system.
- Dissolved oxygen and conductivity measurements taken near the entrance were around 6ppm and 33 mS/cm respectively before the opening and 14 ppm and 55 mS/cm after the opening.

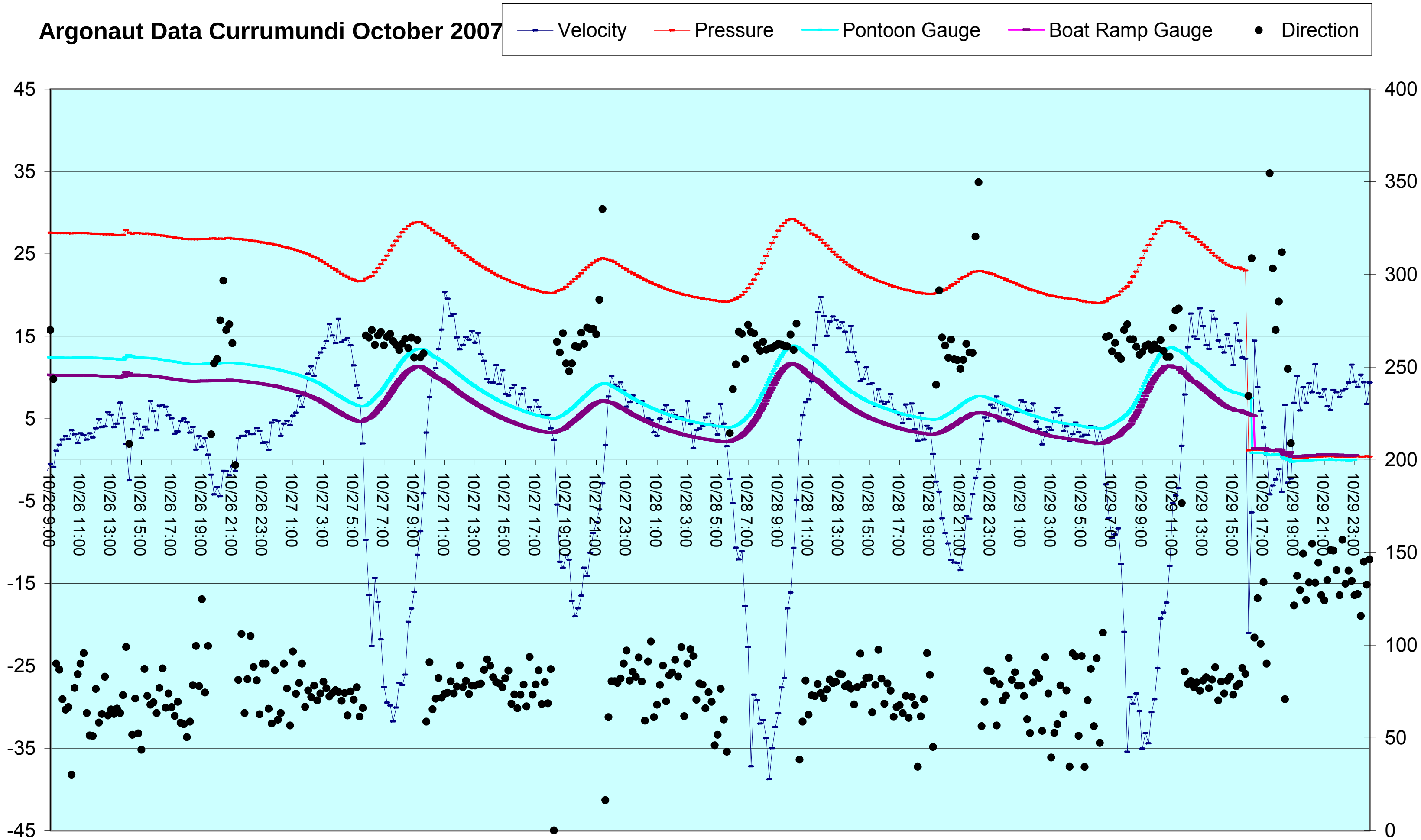

Figure 36: Continuous Velocity and Pressure Measurements - July 2007

7.2 MAJOR FIELD EXERCISE – MAY TO JULY 2008

Griffith Centre for Coastal Management (GCCM) in collaboration with the University of the Sunshine Coast (USC) conducted a co-ordinated research fieldtrip in relation to the lake dynamics from 22 May to 9 July 2008.

During the month long research period tidal data was recorded continuously and weekly surveys of the lake entrance were conducted in order to understand the entrance movements. Current velocities were recorded during a two week intensive study period, with water quality measurements being collected by the University of the Sunshine Coast. These water quality data are discussed in Chapter 5. Hydrodynamic and water quality data was collected along different sites in Lake Currimundi as shown in Figure 37.

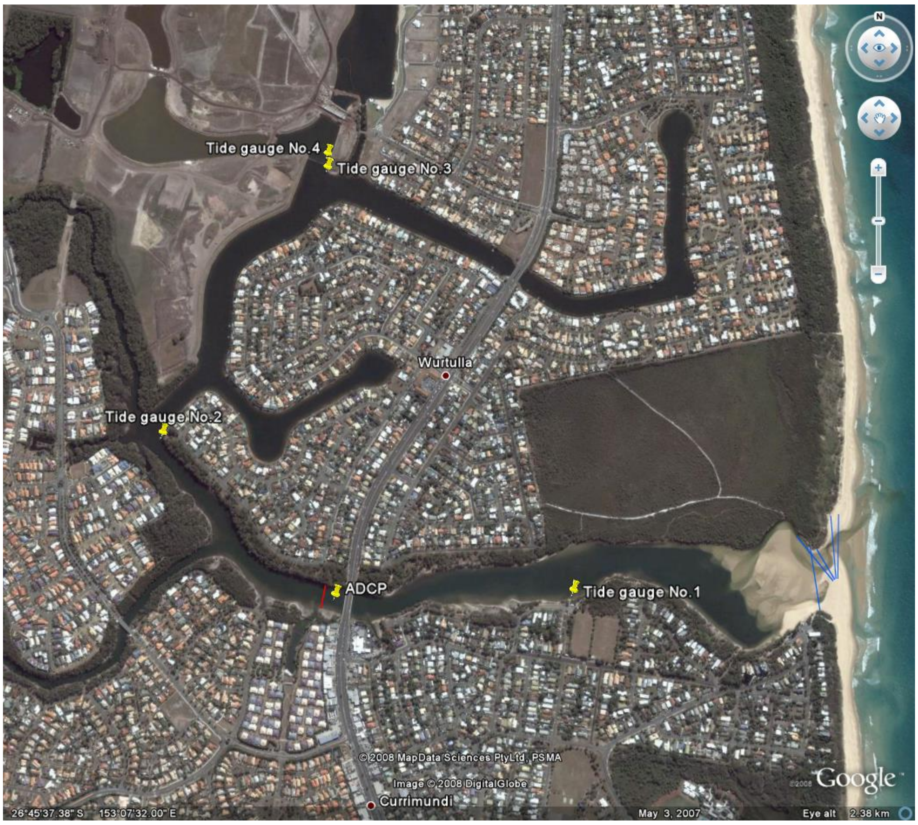

Figure 37: Location of the different sites in the lake (Source: Google Earth). The blue lines represent the survey lines at the entrance. The red lines represent the localisation of the transect lines.

7.2.1 Entrance Morphology

During the research period, six entrance surveys were completed in order to map any changes in the entrance morphology. These are first attempts to define the nature of the entrance channel. The first survey was conducted on 23 May 2008 while the entrance to the lake was closed (Figure 38). Due to strong water currents and water depths, the second entrance survey was only partially completed. This occurred after the opening of the lake's entrance on 24 May 2008. Following this, four more surveys were conducted in June and a final survey in July (Figures 38 to 42).

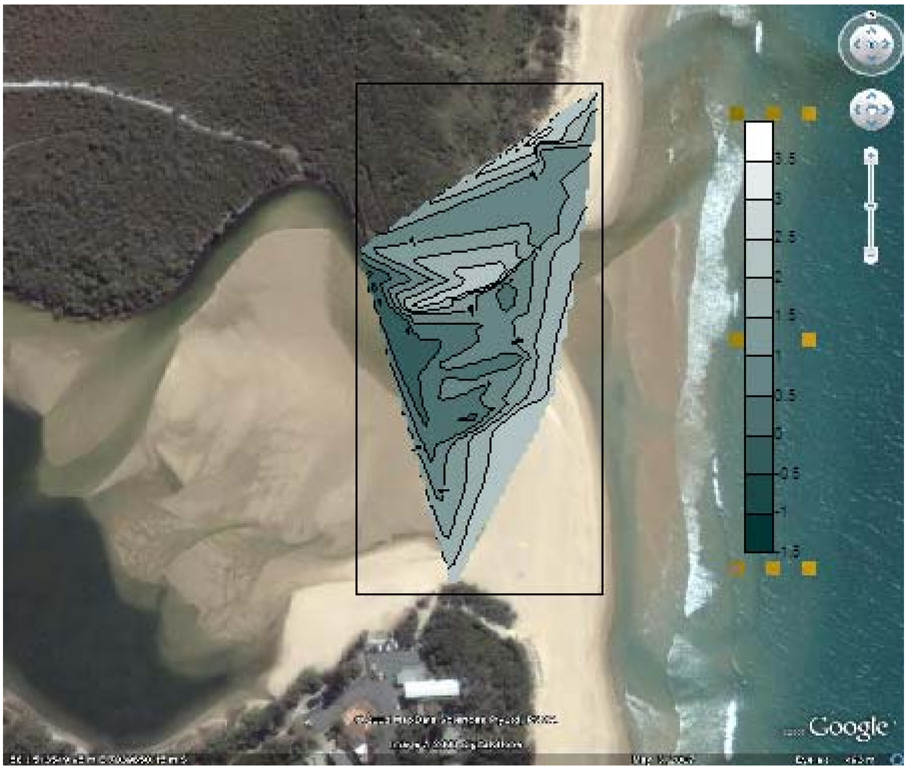

Figure 38: First bathymetry of the entrance when the lake was closed

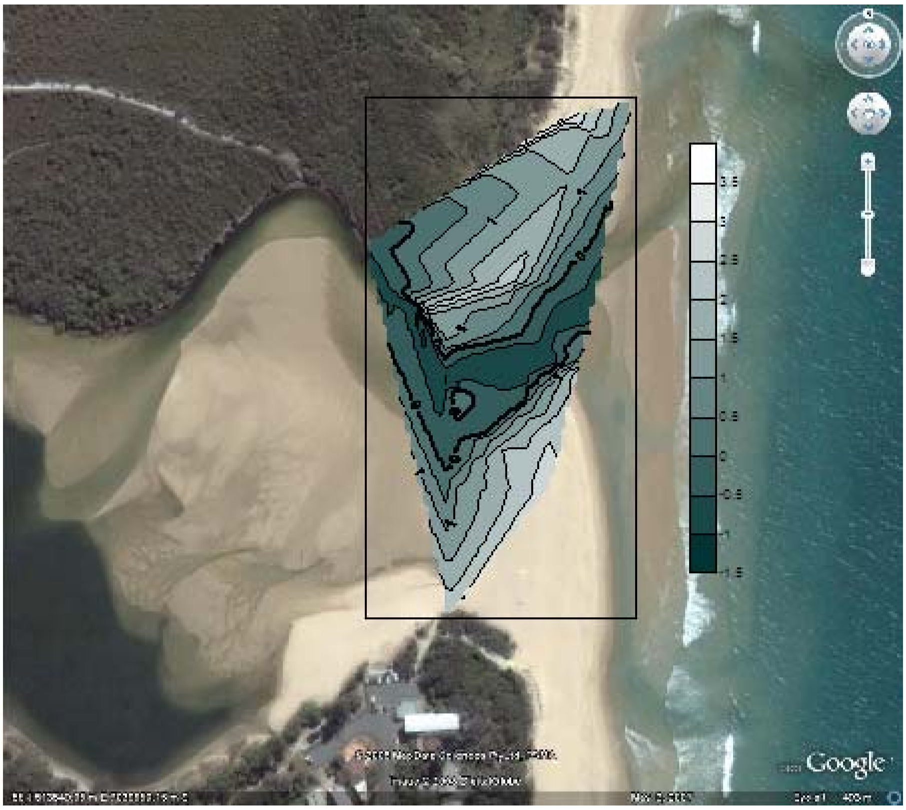

Figure 39: The survey of the 3rd of June 2008 after the opening

Figure 40: The survey of the 6th of June 2008

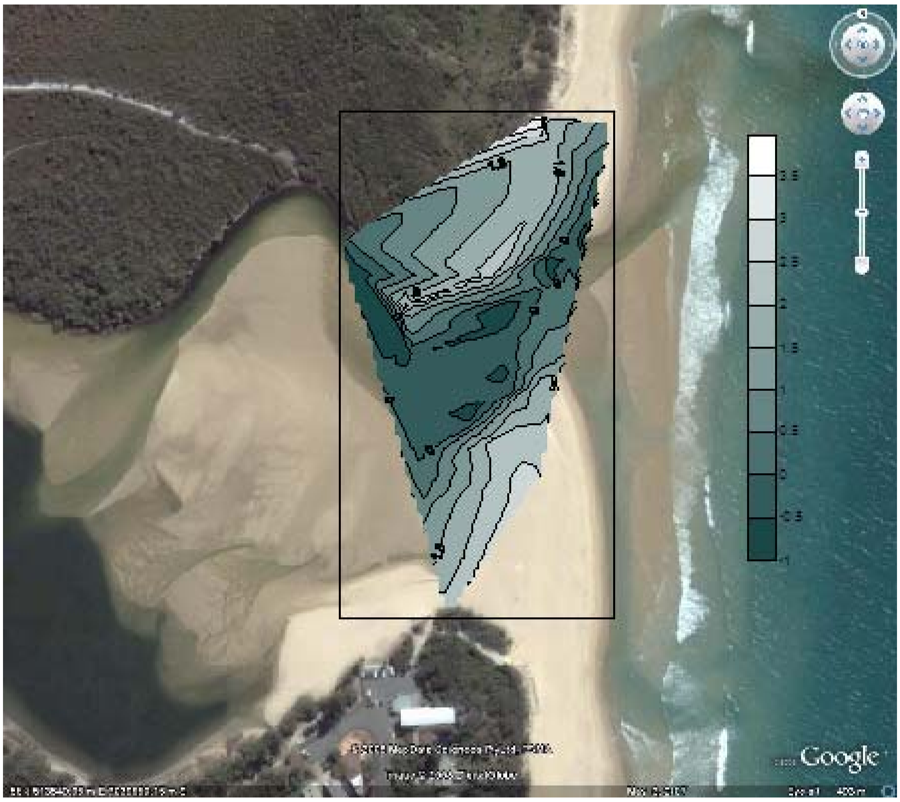

Figure 41: The survey of the 12th of June 2008

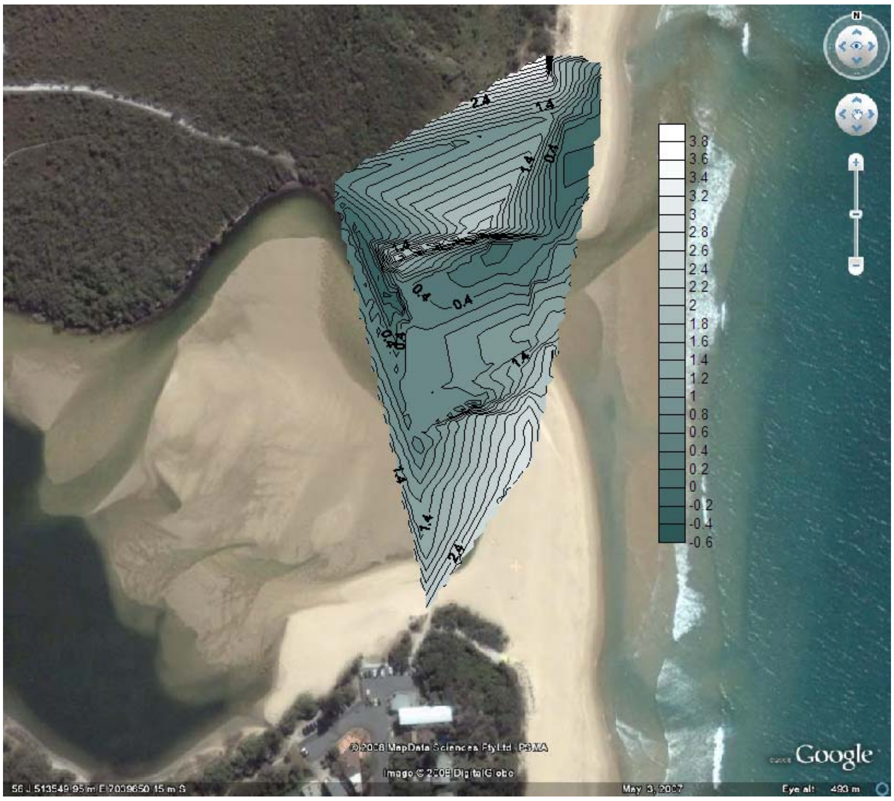

Figure 42: The last survey on July 9th 2008

Daily changes in the entrance morphology were noticed and recorded especially after the entrance was opened on 23 May 2008. Some changes noticed included the natural removal of excess sand left after the entrance opening, the ever changing depth and location of the entrance channel and the gradual exposure of rock along the environmental park.

7.2.2 Tidal influence in the lake

Data collected during the spring tide on June 4th and a neap tide on the 11th June show that there is a difference of three to four hours between the ocean tide and the recorded tide in Lake Currimundi during low tide and a difference of 45 minutes to 1 hour and 30 minutes during high tide.

The overall tidal characteristics for the system are shown in Figure 43. Some key findings are:

- The build-up of water level in response to the high rainfall preceding the opening is shown
- The tidal signal remains evident throughout the data collection period
- The attenuation in the tidal signal is evident as the overall tidal exchange reduces

Utilising the tidal discharge relationships (Figures 44 and 45) it is possible to estimate typical tidal prism values during spring and neap tides. Using the data for the first established tidal signal following the opening (4 June 2008), a tidal prism volume of approximately 910ML was calculated. For a neap tide (11 June 2008) a tidal prism volume of approximately 250 ML was calculated.

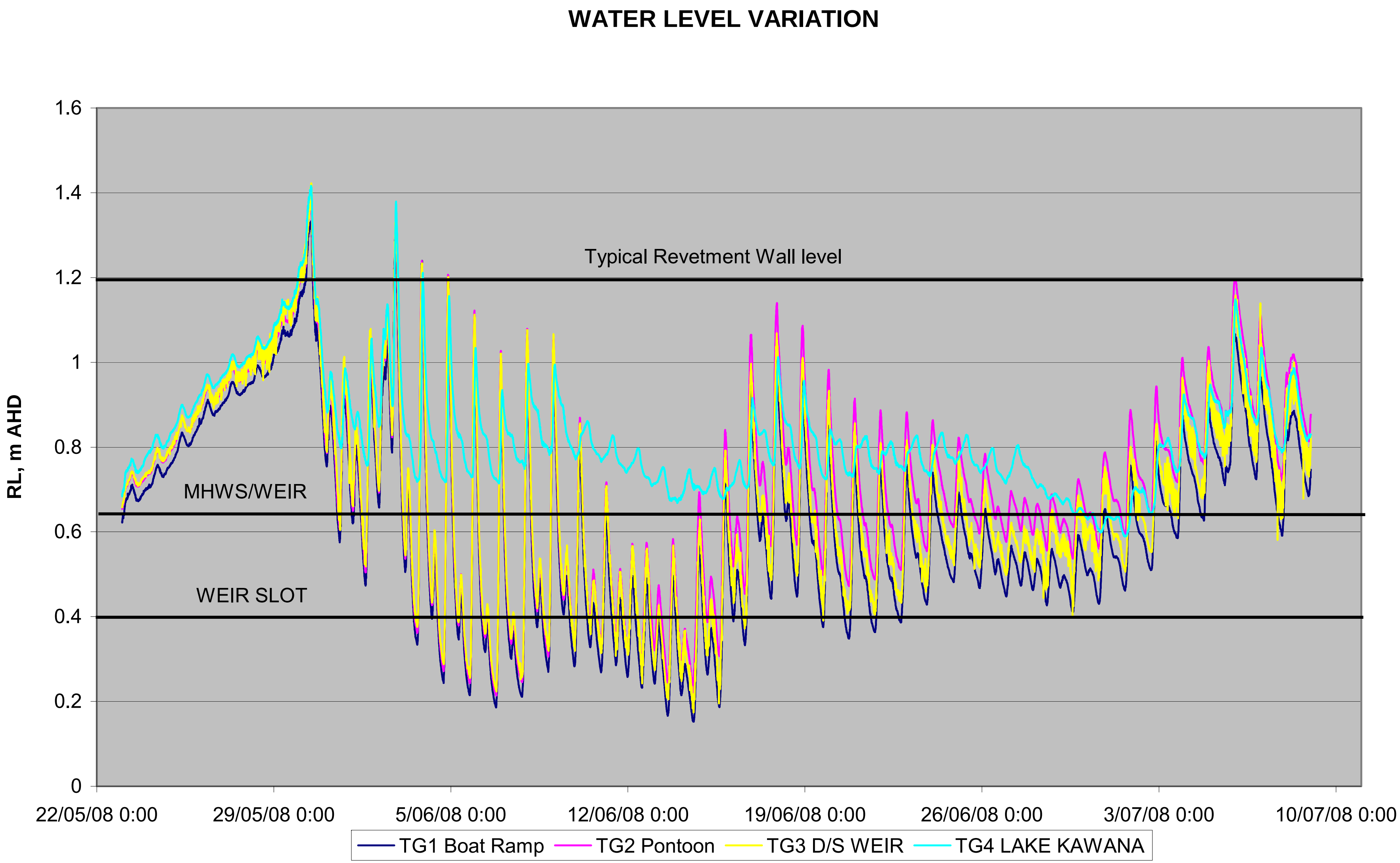

Figure 43: Water level variation June/July 2008

For both of these tidal cycles, the entrance was open with a reasonably well defined entrance channel (see Figure 38 to 42). A more typical condition is one when the entrance is a wide very shallow channel. Under these conditions, the entrance would be classified as closed or nearly-closed from a point of view of there being very limited tidal range in the lake. Measurement using the velocity profilers is not possible under these circumstances. An estimate was made of this base flow during a field inspection in summer 2007, when the entrance channel was estimated at 30m wide and 300mm deep. The average velocity was estimated at 0.8m/s resulting in an estimate tidal prism of approximately 100ML.

Based on the quoted figures for the pumped discharge through Lake Kawana of 82 ML on an average tide, it can be seen that it is most likely that the Lake Kawana flow is responsible for maintaining the entrance "nearly-closed", rather than closed.

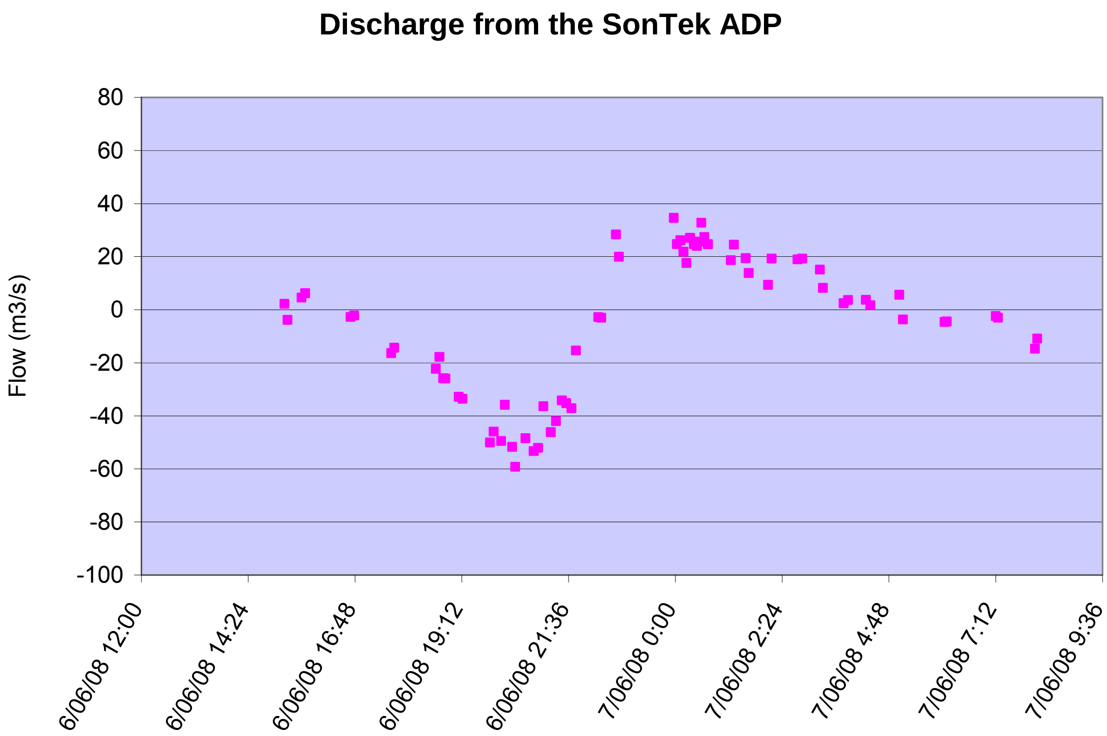

Figure 44: Discharge from Transect on Spring Tide 4 -5 June 2008

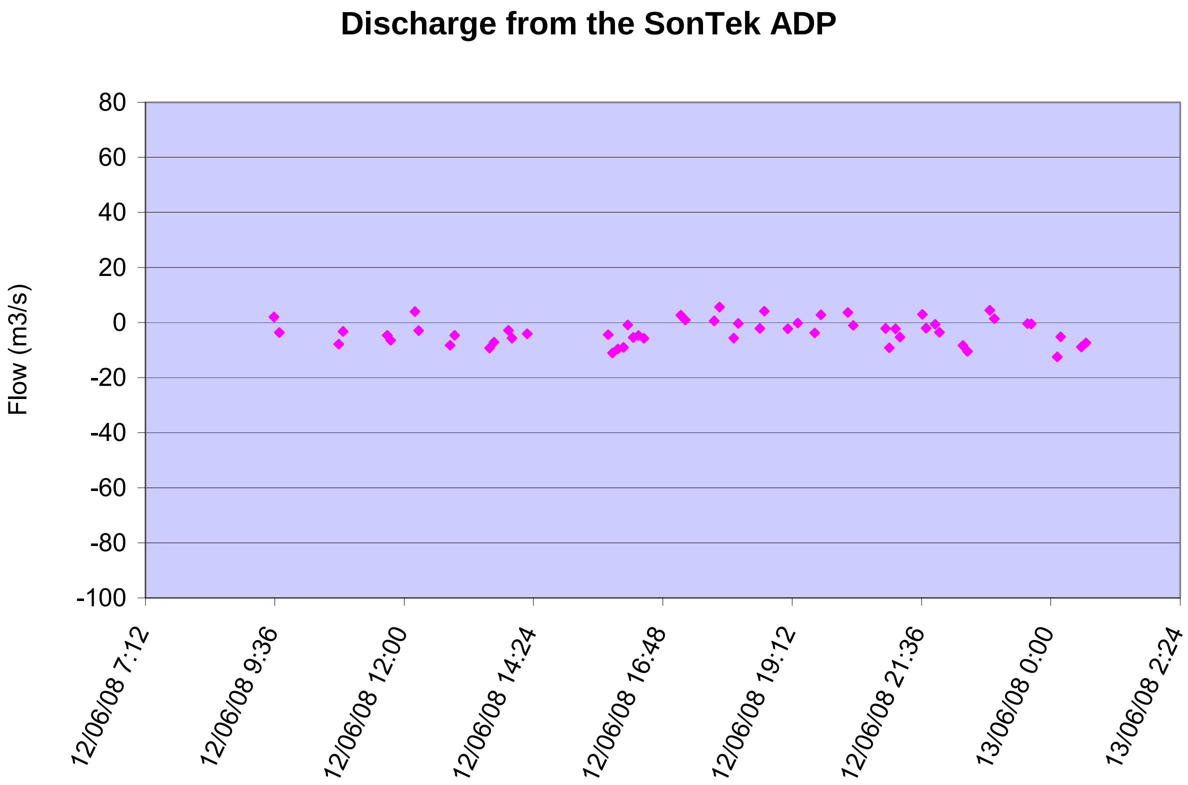

Figure 45: Discharge for Transect Neap Tide 11- 12 June 2008

7. 3 HYDRODYNAMIC MODELLING

A model of tidal dynamics was established using the MIKE21 modelling framework held by Council, and run by Council's consultants SKM in Brisbane. The model is used for catchment-wide hydrological and hydraulic studies, and does not include detailed configuration of the Lake Currimundi entrance.

A more detailed bathymetry for the lake was established using Council data, and the detailed entrance bathymetry obtained during the field exercise as proposed in the original study tasks (See Appendix 3). Tidal height and velocity profiles were also used to calibrate and validate the model.

It originally proposed to undertake advection-dispersion modelling and calibration as part of the Study. Based on the new understanding of lake dynamics obtained in this study, this activity was not considered necessary due to the well-mixed nature of the flow and the rapid flushing which occurs during opening events. Resources were also limited due to the effort placed on the hydrodynamic and water quality monitoring in July 2008. Consequently a proposal for more detailed water quality, sediment transport and ecological modelling (See Appendix 3) is not presented as the on-off nature of the lake dynamics would suggest that this type of expensive modelling activity is not justified.

A subset of the overall model was run covering only the areas of tidal influence in Lake Currimundi and Lake Kawana. The weir was included and typical head-discharge relationships were applied to flow across the weir. At the entrance the flow was constrained to a channel of dimensions determined in the survey and friction coefficients were applied based on earlier modelling studies.

The model was initiated under the static conditions just prior to the opening of the entrance and then run over a number of tidal cycles as the tidal flow was established in the lake and subsequently reduced as the entrance in-filled again.

Results are shown below in Figure 47 for tidal elevation at 4 sites as shown in Figure 46. These sites included the boat ramp near the entrance and close to the location of the ADCP current meter; at the pontoon some distance upstream and on either side of the Lake Kawana weir. The results show excellent correlation between the measured tidal height and the output of the model. This result is perhaps not surprising because, as stated earlier the system behaves uniformly except for the entrance channel. These results give confidence in the use of the model for scenario testing in the absence of field data for the various conditions. A protocol for model scenario testing for a subsequent event is presented in Appendix 11. This protocol assumes some warning of a natural or artificial opening, and sets out basic data collection requirement to allow for quasi-calibrated computer runs.

Figure 46: Location of Model Output Sites

The velocity distribution associated with a typical spring tide some days after the opening are shown in Figures 48 and 49 for an ebb and a flood tide. The maximum velocities are evident in the entrance channel, with average velocities below 0.2m/s in the main channel.

During the flood tide average velocities are considerably higher as expected with higher velocities extending up to the pontoon location.

The calibration of the model against measured average discharge values calculated by the Sontek ADCP software as shown in Figure 50 is excellent, again giving confidence in the use of the model as an operational component of the adaptive management framework, or to undertake scenario testing in the event of a proposal to make a major modification such as a repeat of the 2004 sand plug removal.

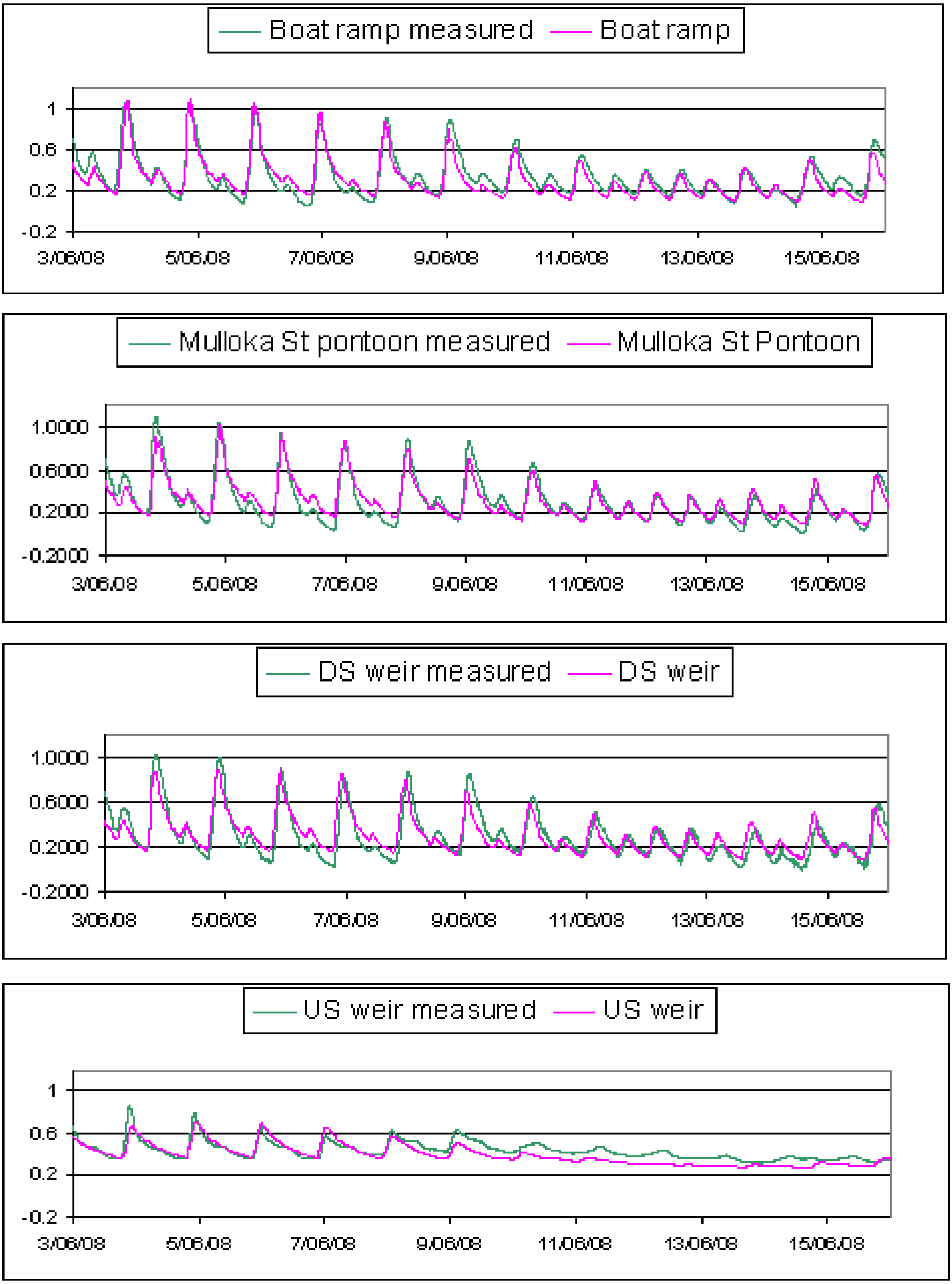

Figure 47: Hydrodynamics Model Water Level Calibration

Figure 48: Maximum flow velocity during a spring ebb tide

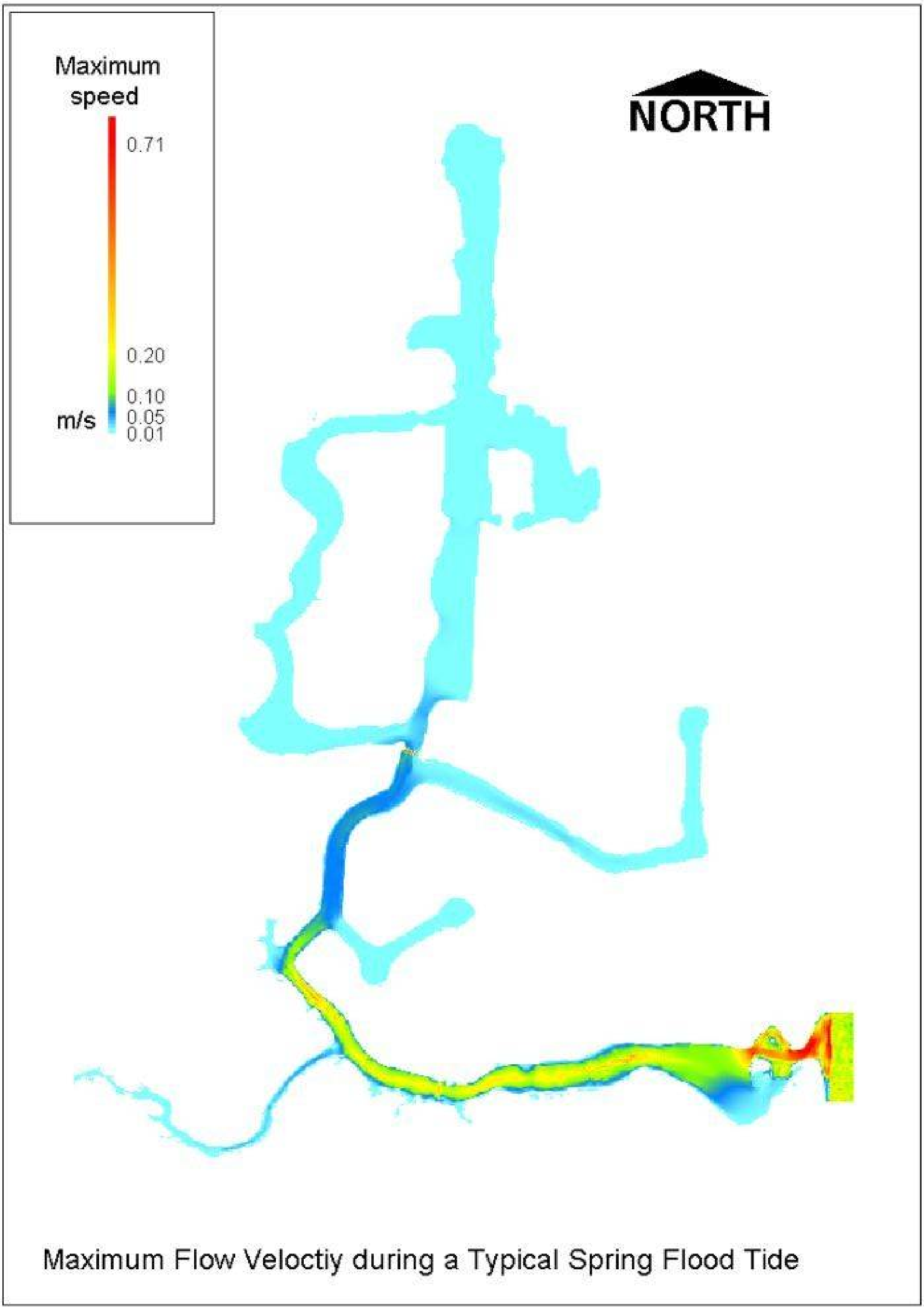

Figure 49: Maximum flow velocity during a spring flood tide

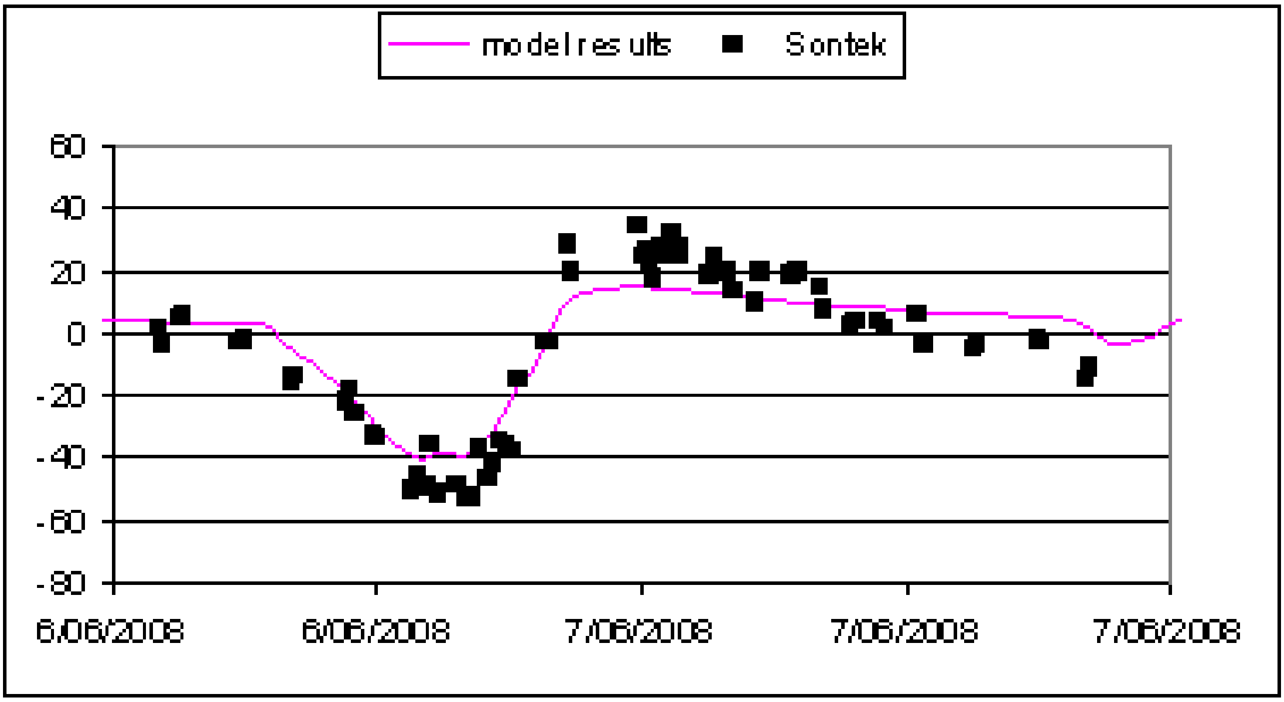

Figure 50: Model Discharge Calibration

7.7 PHYSICAL PARAMETER MONITORING

Throughout the field exercises the parameters which have been monitored are:

- Water level
- Water flow velocity
- Discharge (by calculation)
- Temperature
- Conductivity
- Dissolved Oxygen

From the results that have been obtained from the various field measurements and from the modelling activities, it is evident that there is considerable temporal variation in water level during a freshwater flooding event and during artificial or natural openings of the entrance. As water level variation is directly related to tidal velocities and discharges, it is recommended that the only long-term monitoring requirement for physical parameters is for a water level recorder to be installed at a convenient and secure location. Given that there is very little spatial variation in water level throughout the lake it is not critical where it is located.

Details of this installation are provided in Appendix 11 and should include telemetering to provide a real-time management capability.

In the original project brief it was proposed that a permanent velocity monitoring site be established. However, given that velocities are so low unless there is either a flood event or a major entrance breakthrough, it is considered that further velocity measurement should be limited to a set of tidal gauging during closing and opening sequences, similar to that of June 2008. It is recommended that 3 more such events as outlined in Appendix 11, be monitored to provide a more robust validation of the computer model under varying entrance channel characteristics. Detailed bathymetry of the entrance channel and shoals will need to be undertaken during each event.

7.8 OTHER LONG TERM MONITORING SYSTEMS

Other chemical parameters are covered under the recommendation for water quality monitoring in Chapter 5. Catchment monitoring – in particular, bank erosion, vegetation condition, fish and benthic communities has been addressed in part in Chapter 4. It is recommended that the most effective way of maintaining a database on these aspects is to engage with the catchment community groups to maintain a register of changes that occur in the Lake which can be correlated to environmental parameters and physical lake characteristics and management activities.

This should be complemented by regular surveys of fish, benthic communities and riparian vegetation. Such surveys could be cost-effectively undertaken in partnership with the University of the Sunshine Coast as student projects.

7.8.1 Coastal imaging

A trial was proposed as part of the project brief to examine the effectiveness of a video imaging system. Arrangements were put in place to mount a Coastalwatch P/L camera on a high-rise inside the entrance which would have yielded images similar to that of Figure 51. At the same time, discussions were being held between SCRC and Coastalwatch P/L regarding placing a camera on the surf tower for their normal surf webcam service. The rationale behind the use of the video camera was that research and development work being undertaken by Griffith University and Coastalwatch P/L allows for an automatic identification of the line between water and land, thereby defining the channel location at low tide. As this data would be available on a daily basis the movement of the channels and shoals could be monitored providing a quantifiable assessment of channel movement and the extent of entrance infilling. These data would be useful for the management of the berm, and would provide a surrogate for detailed entrance bathymetry needed for the computational modelling.

After delays due to logistical problems, and difficulties with gaining access to the camera site, a trial camera was installed on *The Entrance* building providing imagery as seen in Figure 52. This camera was operational during the field exercise in June and July, and the images have been archived. Analysis of the images was not attempted, and the camera was removed due to on-going access issues in the building.

More recently, a camera has been installed at the surf tower, and trials have been undertaken to apply the methodology developed on the Gold coast to use this camera to define the entrance channel location. The trials suggest that the surf tower is a suitable location for a camera to define the entrance channel migration across the face of the lake mouth, but not more detailed definition of the channel and flood shoal area further inside the lake. However, the advantage of the beach camera site is that other information can be obtained pertaining to the condition of the beach as it relates to entrance conditions.

It is recommended that this approach to entrance monitoring be established and incorporated into beach management and surf safety programs. For example, the Griffith Centre for Coastal Management in partnership with Coastalwatch P/L is undertaking an assessment of the shoreline position of Gold Coast beaches based on camera imagery. This kind of assessment is not a complete substitute for hydrographic survey of beach profiles, but acts as a surrogate for beach health and erosion/accretion cycles. The information obtained from the video imagery can also be used to develop a beach safety hazard rating system. The cost of establishing an integrated camera system for monitoring this broad range of parameters is estimated to be approximately $20,000 for establishment costs with annual analysis costs varying depending on the number of parameters being reported on.

Figure 51: View over entrance shoals October 2007

Figure 52: Webcam images from *The Entrance* building

CHAPTER 8 - ENTRANCE OPTIONS

8.1 INTRODUCTION

Lake Currimundi, prior to the major modifications of the last few decades, operated as an ICOLL (Intermittently Closed and Open Lake or Lagoon). The entrance was generally closed with a berm of sand blocking any tidal flow between the lake and the ocean. Breaches of this berm would have occurred during high rainfall events or as result of overtopping during high tides or storms. The processes of sand movement along the beach would result in rapid closure of the entrance again.

In its current configuration the lake is generally open to the ocean, albeit only to a limited extent. The lake now has a persistent outflow due to the pumped discharge from Lake Kawana, and during spring tides or higher, there is also a greater tidal flow.

In the past the management of the lake water quality and biting midge problem has been done through the management of the sand berm across the lake entrance. The berm is also an integral part of the beach littoral system, and the extent of the berm and the degree of opening of the entrance affect the stability of the adjacent beaches.

In this chapter the nature of the coastal processes influencing the lake entrance will be discussed as will the options available for managing the entrance and the stability of the adjacent beaches. These include the construction of a rock wall stabilizing the adjacent beach and berm, and a berm height management strategy.

Although not explicitly identified as a task for this study, a discussion on climate change impacts will be included as will reference to the recent requirement of the state government for a Shoreline Erosion Management Plan (SEMP). As part of an SEMP, detailed costings of options would be undertaken. Consequently because of this and resource limitations due to the cost of the July 2008 field work and the effort expended on non-specified tasks such as bank erosion assessment, a detailed cost-benefit analysis has not been undertaken.

8.2 COASTAL PROCESSES OVERVIEW

Sand is transported along adjacent beaches by the combined action of waves and currents. The prevailing waves are both ocean swell and locally wind-generated ‘sea’. The swell waves are of long period (typically 7-12 seconds) and propagate to the shoreline from the deep ocean. They experience significant modification by refraction, bed friction and shoaling, particularly under the influence of the northern banks of the entrance to Moreton Bay. The “sea” waves are of relatively very short period (generally less than 4 seconds) and are not substantially affected by the offshore bathymetry prior to breaking nearshore.

The waves have three key effects on sand transport, namely:

- They break and generate so-called radiation stresses, particularly within the wave breaker zone where wave-driven longshore currents may result;
- Their orbital motion impacts on the seabed causes bed shear stresses that mobilise and put into suspension the seabed sand. Their asymmetry in shallower water causes a significant differential in the forcing on the bed sediments, stronger towards the shoreline in the forward direction of wave travel leading to an onshore mass transport of sand; and

- They cause a bottom return current in the surf zone, strongest during storms when they typically dominate over the mass transport and move sand off the beach to the offshore area.

Currents generated by the tide, waves and wind provide the primary mechanism for the transport of the sand that has been mobilised and put into suspension by the wave/current action.

Generally, at a typical beach location, sand transport may be regarded in simple terms as involving longshore and cross-shore sand movement processes. These act concurrently and interact.

Cross-shore sand transport involves:

- Erosion of sand from the upper beach and dune area during large storm wave events, with the sand being taken offshore where it is commonly deposited as one or more shore-parallel sand bars located in the vicinity of the wave break area;
- Subsequent slow transport of the eroded sand back to the beach, often over many months or several years; and
- Transport by the wind of the accreting beach sand back to the dune system where dune grasses act to trap it and build the dune back to its former condition.

Thus, on dynamically stable beaches, there is a balance in the amount of sand that is taken offshore and is subsequently returned to the beach and dune. The wind plays an important role in the natural balance of sand movements and beach and dune stability. If the dune is poorly vegetated, the sand may be blown landward and lost from the active dune system.

Longshore sand transport results predominantly from waves breaking at an angle to the shore with an alongshore component of their radiation stress that drives an alongshore current and carries the sand along the coast. The wind and tide may also contribute to generation of alongshore currents near the beach. This longshore sand transport is distributed across the surf zone and is greatest in the area near the wave break point where the wave height, longshore current and bed shear are greatest. That is, it occurs across a limited zone most probably in water depths less than about 5-8m.

The beach may remain stable (without net recession or accretion) where the longshore sand transport is uniform along the coast. However, where there are differentials in the rates of longshore transport, including any interruption of the sand supply to an area, the beach will erode or accrete in response.

Because longshore and cross-shore transport co-exist, a net sand loss of sand in the nearshore part of the beach profile caused by a negative longshore transport differential may not manifest immediately as erosion of the upper beach. However, more sand would be taken from the beach when storm erosion occurs and, to maintain the normal equilibrium profile shape within the active zone, less sand is subsequently returned to the beach/dune than was previously there. This leads to a recession of the shoreline.

At the entrance to Lake Currimundi the coastal dune system is interrupted by the tidal channel which cuts through the dune. Over time the entrance channel has been located over a distance of some 170m along the shoreline, and as a result there is no permanent dune vegetation in this area, only an un-vegetated sand berm (Figure 53).

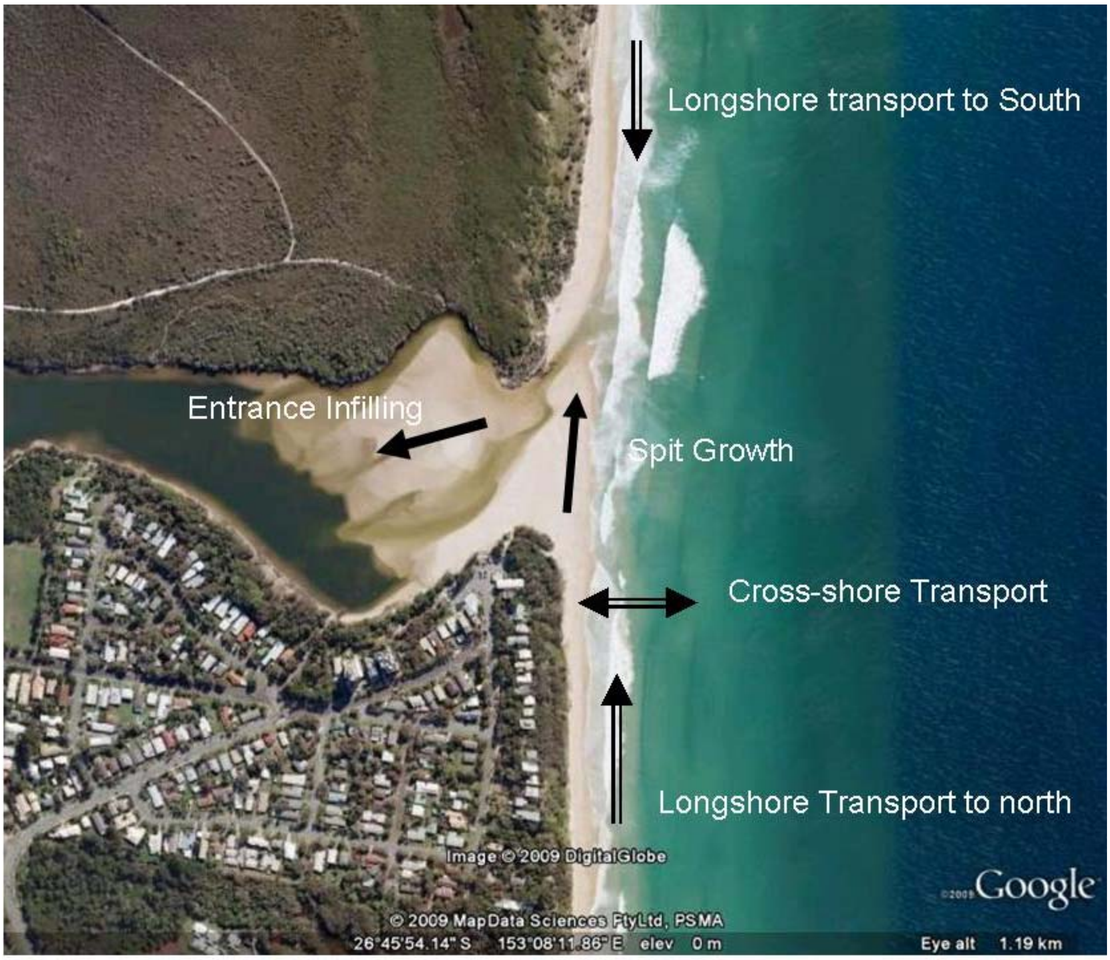

Figure 53: Lake Currimundi Entrance (June 2008) showing the dominant sand transport mechanisms

The entrance behaves as all tidal entrances do, in that the natural tendency is for infilling of the entrance with beach sand, as evident in Figure 53. This infilling process leads to complete lockage under conditions of low or no freshwater discharge. The infilling process is driven both by the wave action pushing sand up the beach, and tidal flow asymmetry. This asymmetry is manifested in flood tides being shorter and having higher peak velocity (and hence sand transport) and ebb tides being longer with lower peak velocities. This feature is clearly shown in the results of the tidal gauging shown in Chapter 7.

The net result of this infilling process is evident following the sand plug removal in 2004. Well over half of the sand removed in that dredging campaign has returned to the entrance shoals which are now propagating further upstream (SCRC data). During spring tides this process is accelerated as the flood flow spreads across the tidal flats inside the entrance.

The results of the gauging and modelling associate with the opening of the entrance in 2008 shows clearly how even a small dredging exercise (when compared to the 2004 sand plug removal) can allow a full tidal exchange to develop throughout the lake, but that it is only a matter of days before the entrance channel infill's and minimal tidal penetration returns to the interior of the Lake.

The entrance channel in its current form is simply a drainage channel for the pumped discharge volume, the wave and tidal flow driven entrance shoal processes dominating.
Because the average flow at the entrance is very low (even now) the dominant coastal process is the cross-shore transport of sand which builds up the berm, thereby blocking the flow from the lake. As the tidal flow is so weak, the longshore transport of sand will also cause the migration of the entrance channel in the direction of the predominant longshore transport. There has been no detailed study of coastal processes at Lake Currimundi in the past, but from an examination of aerial photographs and other evidence it would appear that generally the net direction of sand movement is to the north. This results in the entrance channel discharging along the northern banks. As discussed in an earlier section, there have been a few occasions when the channel has migrated to the southern side and has caused erosion requiring management action. This was the case in 2006 as shown in Figure 54. The management action taken was to artificially fill the channel and to create a new berm forcing the entrance channel back to the north (Figure 55).

Figure 54: Entrance migration to the south in July 2006

Figure 55: Entrance Channel forced to the north following the artificial build-up of the berm in August 2006

The shoreline is subject to a threat of erosion associated with:
- short term storm events; and
- long term recession as a result of a deficit in the overall sediment budget and the influences of climate change (sea level rise).

Beach erosion is a natural process although it can and has been exacerbated in places by the influence of man. If erosion is allowed to occur naturally, the character and amenity of the beach are retained even where the shoreline is receding. Beach erosion becomes a problem when it threatens development, either causing loss or damage of the property or prompting construction of protective works such as seawalls. The essence of erosion problems is therefore not that beaches erode, but that development has occurred within the zone of natural beach movements.

In the case of Currimundi, the potential for erosion impacts in two ways. Firstly, the beach front properties are at risk, and secondly, the entrance berm can overtop exposing the lake to wave action and tidal exchange.

8.3 Beach and Entrance Management Issues

It was well outside the scope of this study to examine all of the beach processes and related issues for a complete assessment of beach management options for the area. This is now in the domain of the requirement for a Shoreline Erosion Management Plan (SEMP) as prescribed by the Department of Environment and Resource Management (DERM – formerly the EPA). Without any intention to pre-empt the findings of a SEMP for the Currimundi area, the following discussion of entrance management options is presented in order to meet the tasks defined for this study.

From the findings of the other components of this study, it is clear that the key design criteria for any entrance and adjacent beach management strategy, are to:

- Provide for cost-effective artificial entrance opening and closing as required to meet criteria for water quality, flooding and biting midge control
- Ensure that entrance channel migration does not lead to scour and subsequent threat to infrastructure, natural assets or property along the entrance channel or adjacent beaches
- Not interfere with the legislative requirements for flood waters from the Kawana development to drain to the ocean
- Not interfere with regional coastal processes

Adjacent beaches are included in this discussion as any change in the entrance configuration could have an impact on the beaches in the immediate vicinity of the entrance. As discussed earlier for example, it appears that a semi-permanent scour channel formed on the beach in front of properties to the south of the entrance during the period that the channel was located on the southern side of the lake entrance, which is related to the dynamics of the tidal flow and ebb delta formation.

The important processes which need to be managed are:

- The migration of the entrance channel
- Berm overtopping during storms or high spring tides
- Beach front storm cut

8.4 GENERIC OPTION CONSIDERATIONS

A range of generic management options are available for consideration, which may be classified in terms of their consistency with natural coastal and environmental processes and the natural character and values of the coastline as follows:

"Soft" Options: Options which restore and/or preserve the natural character, behaviour and values of the coastal system. These will ensure the sustainable existence and natural character of the sandy beaches, entrances and dunes such that future erosion, both during short term storms and over the longer term, can be accommodated in a coastal buffer zone without threat to development requiring protective works.

Soft options may include works such as beach or berm nourishment with sand or planning solutions that require development to be outside the zone of potential erosion (buffer zone), including:
• regulatory controls on building in undeveloped areas;
• removal of existing development from erosion prone land, and/or
• works aimed at restoration of the beach/dune system seaward of the development to provide an adequate buffer width to accommodate erosion.

"Hard" Options: Options that involve construction of works either to form a barrier to natural coastal erosion to protect development (seawalls) or to alter the natural processes to change the way in which the beach behaves (groynes and breakwaters) or the tidal dynamics of the estuary (locks or entrance training).

Combinations of options or "hybrid" management approaches are often the most suitable where existing development lies within the erosion prone area. For example, works options such as terminal protection (seawalls) are sometimes combined with partial set-back of development, or may be augmented with ongoing beach nourishment to offset associated deleterious environmental and recreational amenity impacts. In addition, most options need to be supplemented with relevant amendments to local planning controls.

Thus, engineering works options for Lake Currimundi Entrance and adjacent beaches may include 'soft' or 'hard' solutions, or a combination of both. The most common feasible works options for overcoming entrance migration and beach erosion problems include the following and are discussed in more detail below:

- beach and berm nourishment with sand to restore or manage the beach and dune system;
- seawalls to protect property;
- groynes to control the longshore movements of sand;
- offshore breakwaters or submerged reefs to modify wave processes which erode the beach.

In addition the concerns over fluctuating water levels inside the lake could be met by

- controlling the flow between the lake and the ocean by either:
  - constructing entrance training walls and attempting to keep the entrance fully open, or by
  - constructing a lock/weir system to control the water level.
- Artificial opening and closing programs

Such works options are generally expensive, typically in the range $2000 to $5000 per metre length of beach to construct for adequate storm erosion protection for example, and the 'hard' structural options typically have adverse side effects on the beach system. Ongoing maintenance requirements must be considered in both the design and financing.

8.5 Options Assessment

A number of the options mentioned above would be considered as part of a SEMP for beaches in the region. In terms of the entrance stability and lake dynamics only the following will be considered:

- Training walls
- Lock/weir system
- Berm height management
- Artificial opening/closing (effectively a Business-as-usual option)
- Seawalls

8.5.1 Training Walls

The usual approach historically for controlling a mobile tidal entrance is to construct rock training walls. The Currumbin entrance on the Gold Coast (Figure 56) is an example of a trained entrance with similar characteristics to Currimundi. The advantages of entrance training are:

- Stabilisation of the location of the entrance alongshore, and hence minimising the potential for scour of the banks
- Improving the tidal flow and channel navigability.
- Increasing tidal flushing
- Improved flood conveyance (if kept open)

The disadvantages are:

- Cost ($5 – 10 Million)
- The disruption to beach sand movement with the possibility downdrift erosion and the need for entrance by-passing ($10s of Millions)
- Destruction of the "character" of the entrance
- If entrance is to be kept open, maintenance dredging will be required, as training walls do not provide a long term control on entrance infilling – as is the case at Currumbin and all other entrances

Figure 56: Currumbin Entrance

A possibility for an entrance training option is to construct walls on a preferred alignment to control the entrance channel, but to allow these walls to be partially buried and project no further seaward than the current berm. This would have the benefit of prevention of bank scour and control of the channel location, without the negative impacts of conventional training walls. This option would still require an artificial opening/closing strategy to maintain the other criteria for the Lake.

8.5.2 Lock/weir system

An option for controlling the water level and flow throughout the lake is to construct a lock and/or weir system across the entrance. A similar system is in place at Glenelg in Adelaide as shown in Figure 57.

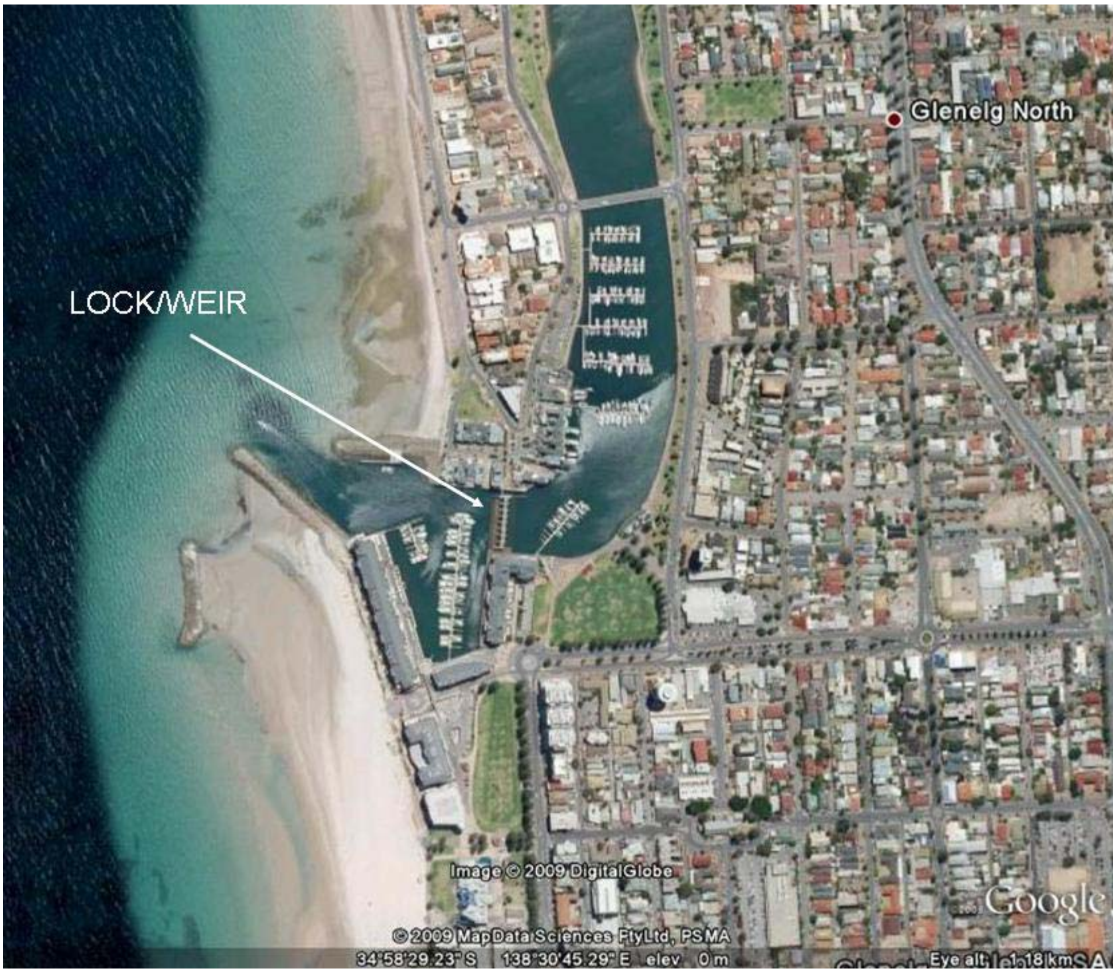

Figure 57: Lock and weir system at Glenelg, South Australia

In the case of Glenelg the purpose is to allow passage of boats out to sea, but also to maintain a near constant water level in the lake system. Given that Lake Currimundi does not have, nor is likely to have, this level of boating activity, a simpler weir system could be adopted to control water level in much the same way as the Lake Kawana weir does. The weir could be constructed right at the entrance, or further upstream. Construction at the entrance would require some kind of piped outlet for normal flows with high flows discharging over the weir.

The advantages of this option are:

- Minimisation of water level fluctuations in the lake
- Minimisation of entrance scour (provided the weir is constructed across the entrance as a seawall
- Deepwater recreational amenity behind wall (after dredging to clear existing entrance shoals
- Minimisation of impact on beach processes, unless erosion undermines the structure.

The disadvantages are:

- Costs ($Millions)
- Decrease in water quality due to less tidal flushing
- Loss of “character”
- Loss of sand-flat recreational amenity

8.5.3 Seawalls

This option constitutes a "last-line-of-defence" strategy whereby a seawall is constructed on an alignment to protect property and other natural assets, and to preferably have the wall covered with sand unless it is exposed in a major storm or scour event. This strategy is adopted along the entire developed coastline in Gold Coast City, where the wall is referred to as the "A" Line. In the context of entrance management, the seawall would be constructed from locations well within the entrance, and continue out onto the adjacent beaches as part of a SEMP option. The nature of the dunal systems in this area have been examined in a preliminary geotechnical investigation. Of interest is whether there is substantial indurated sand in the area which would provide added coastal protection. The report on this investigation is included in Appendix 12, and it is recommended that further investigation be undertaken.

The seawall could be constructed of rock, or form other materials such as concrete armour units or sand-filled geotextile containers. This technique is in use as an emergency action at the mouth of the Maroochy River as shown in Figure 58.

Figure 58: Geotextile seawall as the Maroochy River entrance

The advantages of this option are:

- Prevention of bank scour due to entrance channel migration
- Integration with beach management strategies

The disadvantages are:

- Cost $5,000 per linear metre
- No impact on other lake management concerns
- No role in control of entrance opening/closing

8.5.4 Artificial Opening/Closing

For some time, the lake has been managed by either opening or closing the entrance with mechanical equipment out of step with the naturally forced opening and closing. This is a standard practice for ICOLLs in NSW.

The advantages of this are:

- Flexibility in responding to emerging problems such as midge, water quality and flooding
- Relatively low cost compared with permanent structural options
- Only short term loss of character and amenity
- Adaptable to future changes such as increasing catchment development

The disadvantages are:

- Management is part of the on-going operational budget, rather than a one-off capital expenditure
- Extent and cost of actions are variable depending on conditions

A special case of artificial opening is the extensive dredging required to remove the sand plug in 2004. From the various analyses undertaken in this report it is recommended that such large exercises be avoided, as there is no clear evidence of any medium to long term benefit, and some indication of negative impacts. The principal concern with the build-up of the plug to the extent it reached in 2004 is the impact of major floodwater conveyance. Studies of the role of sand bars at the entrance to Currumbin and Tallebudgera creeks on the Gold Coast (Castelle, 2006) demonstrated their role in increasing the upstream flood water levels during the rising limb of the flood hydrograph. Also, given the legislated requirement for Lake Currimundi to be the flood outlet for the Kawana development, there is a view that the sand plug should be removed regularly.

The basis for the recommendation that entrance dredging be minimised is that there is rapid infilling of entrance following the 2004 dredging. Consequently it is likely that flood water conveyance would have been restricted soon after the plug removal regardless. It is not feasible to keep the entrance fully open, hence a more appropriate strategy for flood management would be to undertake more regular small scale channel dredging, and to remove the landward edge of the entrance sand flat as discussed elsewhere. From the data obtained in the 2008 field exercise, it is evident that following an entrance opening (and presumably during the rising limb of a flood) there is a rapid scouring of the entrance channel and an equally rapid reduction in maximum water level upstream in the lake. This opening was in response to the rapid increase in water level following the period of high rainfall in May and June 2008, and it is expected that a similar rapid response to dig out the entrance channel can occur in the future.

8.5.5 Berm height management

This option has been adopted in the past as part of the entrance management strategy for Lake Currimundi and other locations. This action entails the maintaining of the berm across the entrance at a height and width determined to optimise the stability of the entrance channel and to minimise the breaching of the berm under high spring tide and storm conditions. Recent experience in August 2006 (Figure 59) demonstrated the benefits of berm management, when as part of the relocation of the entrance channel away from the southern bank the berm height was raised and width increased. Berm management can be undertaken quickly, provided relevant approvals are in place and offer flexibility of response dependent on availability of funding and equipment.

Prediction of berm height as a function of wave climate is still the subject of basic research (eg. Weir et al, 2006). The general indications are that the ultimate height of the berm will be approximately limited to the wave run-up for a given wave condition. Berm overtopping and reduction in berm height will occur for storm events.

In general it is considered that the berm should be kept as high and as wide as possible. A level of 2m above spring high tide and with a width of at least 50m at that tide level would be recommended.

The advantages of this are:

- Prevention of overtopping with consequent increase in sand infilling and wave penetration
- Maintenance of a preferred entrance channel location
- Improved protection of adjacent beachfront

The disadvantages are:

- No impact on other lake issues such as water quality and biting midge
- Need for regular maintenance
- Allows dredging of localised deeper water swimming areas behind the berm without the risk of enhancing breakthrough

Figure 59: Berm constructed in August 2006 as part of entrance channel relocation

8.6 RECOMMENDED OPTIONS

Hard structural options for entrance management are not considered appropriate for Lake Currimundi due to their cost, their impact on the character and amenity of the lake and their inflexibility and incompatibility with the process of adaptive management. Indeed it is highly recommended that the current strategy of artificial opening/closing and berm height management continue.

In line with the adaptive management framework, it is proposed that the current artificial closing response to the need to control biting midge be carried out according to the specifications set out in Chapter 3. During the subsequent opening, any dredged material should be placed on the berm. This should also be the procedure for any dredging inside the entrance for amenity or midge control purposes. In event of a natural breakthrough or migration to the south of the entrance channel, sand should be removed from the landward edge of the sand plug and placed on the southern part of the berm with the aim of achieving the widest and highest berm within financial constraints.

In the event of a SEMP identifying a seawall (A Line) as a key component of beach protection, it is recommended that wall be extended inside the entrance for a distance of approximately 150m. As a precursor to the development of an SEMP it is recommended that further geotechnical investigation to establish the substrate in the dunal system be undertaken.

8.7 CLIMATE IMPACTS AND ADAPTATION

Although not identified in the original brief for this study, nor identified as a key community concern throughout the study, it is considered appropriate to include a brief discussion of climate change impacts on the Lake Currimundi system. It should be noted that the findings and recommendations presented in this report have not been developed in the context of climate change, and no attempt has been made to fully analyse the appropriateness of the recommendations under climate change predictions.

8. 7.1 Climate Change Predictions

In the context of the scope of this study, the key climate change impact will be accelerating mean sea level rise, with a likely increase in intensity of storms also of relevance. The latest estimates for Mean Sea Level rise from the Inter-governmental Panel on Climate Change 2007 Report (in Steffen, 2009) gives an expected upper limit increase in sea level by 2100 of 0.9m. In Queensland, the new Coastal Management Plan has recommended 0.8m, whilst other states of Australia are proposing the higher IPCC value. Of course, more recent information is suggesting that sea level rise is accelerating at higher rates than projected, with the State of California in the US adopting 1.4m as a planning level.

There has been very little in the way of prediction of the increase in storm intensity. However, of more pressing concern in this regard is the natural variability that exists in the historical record, and the fact that over most of the last 30 years of rapid development the SE Queensland region has been in a period of relative calm (Helman and Tomlinson, 2008). A return to a stormy period such as that of the 1860s to 1890s or 1950s to 1970s will see very significant erosion and high storm surge levels well in excess of those experienced in recent years.

A key finding of recent research (Steffen, 2009), has shown that in the SE Queensland region the probability of extreme elevated water levels under climate change will increase 100 fold. In other words, a given extreme water level resulting from tide, storm surge, wave setup and run-up will occur 100 times more frequently in 2100.

8.7.2 Implications for Lake Currimundi

- The main implication of these climate change predictions is that the mean sea level is rising at an accelerated rate and that much of the low lying land around the Lake Currimundi system will be inundated either permanently or on a more frequent basis.

- The response of the entrance sand bodies to rising sea level is not well understood, but it is clear that open coastlines will recede and that entrances such as Currimundi will recede landwards as well, with sand infilling further into the lake.

- Higher water levels will penetrate as well, and without modification the Lake Kawana weir will overtop more frequently and provide little barrier to increased water levels in the Lake Kawana development.

- The current ecosystem will be highly modified and bank erosion will continue unabated under rising water levels.

The general response to coastal erosion and inundation worldwide is to either retreat or protect. In the context of open coastlines the retreat option might involve the introduction of property buy-out schemes such as implemented at Narrabeen/Collaroy in Sydney; planning set-back such as at Byron Bay; or legislative actions such as ‘rolling easements” as adopted in some states in the US.

Protection options include the construction of seawalls, coastal protection structures such as breakwaters and groynes, or the use of beach nourishment.

In the context of climate change, these strategies are limited in their effectiveness. Protection structures will most likely result in the complete loss of beaches under sea level rise. Cost effective sources of sand for beach nourishment may not be available.

Retreat options can only work if there are legislative frameworks which allow the transition of ownership of property from the “real estate’ back to the ‘natural state’. In the case of Currimundi a retreat option would most likely require the gradual abandonment of all properties in low lying areas. In order to protect Currimundi, a combination of the Venice (storm surge and high water level barrage) and the Dutch (dykes) options would be required with the community effectively living below sea level.

Dealing with climate change impacts will require considerable community, political and legislative change, but it is an issue which will most likely require action sooner than later. In the context of the issues addressed in this report, much of the findings would not be relevant under a climate change adaptation framework. For example, raising of the Lake Kawana weir may become an appropriate action, and the bank stabilisation actions may be seen as futile.

It is a recommendation of this report that a climate change adaptation strategy be looked at by the SCRC and the community at large. This may be facilitated by the current South East Queensland Climate Change Adaptation Research Initiative funding by the State Government.

However, in the foreseeable future it will still be possible to manage our coastal environments in their current form and under the current level of climate variability in a more effective manner. Consequently, the recommendations and findings of this study are valid and should be implemented.

CHAPTER 9 – LAKE KAWANA INTER-CONNECTION OPTIONS ASSESSMENT

The connection of the Lake Kawana system to Currimundi via the weir structure and other connections have been identified by the community as an issue of concern (Appendix 2). As such, a task was proposed to examine options for modifications to the interconnections in the event that the analysis of ecosystem health and lake dynamics identified a clear indication of negative impacts. The type of option that could be considered for example would be the modification of the weir to be adjustable for variable heights, or other means of modifying the flows from Lake Kawana into Lake Currimundi. A Cost/Benefit Analysis was to be included addressing both the implications for the Lake Kawana development and the state of Lake Currimundi.

9.1 LAKE KAWANA/LAKE CURRIMUNDI INTERCONNECTIONS

Temporary weir
Following the completion of the construction of the main Lake Kawana waterway, a temporary weir was installed to allow, the pumped flow through from the Mooloolah River to discharge into Lake Currimundi and hence out to sea. There has been no measurement of flow across the temporary weir, however it was estimated that approximately 27ML/day overtopped the weir into Lake Kawana on king tides.

Permanent Weir
The permanent weir was completed in 2007 as shown in Figure 60. The overall designed hydraulic performance is summarised as follows based on advice from SCRC Officers.

- Volume of water pumped

The quantity of water discharged over the weir when the pump is operating for 20h per day is 137,000m^3 (137 Ml/day). The current and ultimate pumping rates will both be 1.9m^3/s. The ultimate pumping duration will be approximately 20 hours per day. Currently, pumping is intermittent as required.

- Lake area/volume

The current Lake Kawana surface area is 50.9ha. with an estimated volume of approximately 3.4 million m^3. The ultimate Lake Kawana surface area will be approximately 75ha and the volume approximately 4.9 million m^3.

- Revetment wall and weir levels

The weir is designed to overtop at Mean High Water Springs (MHWS) at Caloundra. This level is RL 0.63m AHD. The final weir length is 60m, most of which is at RL 0.63m AHD, with a central 10m section at RL 0.4m AHD.

The other tide levels of interest are: Mean Low Water Springs (MLWST) = - 0.73m AHD and Highest Astronomical Tide (HAT) = 1.05m AHD. At HAT, the revetment walls which are nominally at 1.2m AHD are often over-topped in Pangali Canal upstream of Lake Currimundi. Lake Kawana water level is RL 0.65m AHD. Lake water level at HAT is RL 0.96m AHD.

Figure 60: Permanent Weir linking Lake Kawana with Lake Currimundi

- Flow across the weir

The actual flow over the weir has not been measured but the following information has been based on advice from SCRC Officers. For Lake Currimundi water levels less than the weir height (RL 0.4m AHD) it can be assumed that the exchange is one-way from Lake Kawana at the pumped discharge rate. The design discharge rate for the pump is 1.9m^3/s. The pump currently operates for 12 hours a day, which results in a volume transferred from the Mooloolah system to Lake Kawana (and ultimately Currimundi lake) of 82ML/day.

The pump exchange system was required by the structure plan approval to achieve turnover of Lake Kawana within 30days once the lake is fully constructed. To achieve this, the pump was designed in the ultimate scenario to operate for 20hrs a day. This would result in a daily exchange volume of 137ML/day.

For Lake Currimundi water levels higher than the weir height, there will be varying levels of water exchange between Lake Currimundi and Lake Kawana in both directions depending on the relative water level in each lake. The actual exchange quantities can be estimated from the hydrodynamic model if required. As can be seen from the water level data collected during the field exercise in 2008 (Figure 43) during a lake entrance opening event there is considerable tidal penetration into Lake Kawana via the weir. Overall however, the requirement of water mass balance will result in a net seawards discharge equivalent to the pumped discharge.

The impact of the increased exchange over the weir during high tides is an increase in the tidal velocities in the main Lake Currimundi channel and an increase in the flushing during high tide periods.

Tokara Canal Inter-Connection
There has been a proposal from Stockland to use an existing stormwater pipeline to pump from Lake Kawana via a circulation pump on the eastern side of the Nicklin Way, discharging lake water to the head of Tokara Canal south of Moondara Drive. The intended function of this pumping system is to ensure adequate circulation in the eastern section of Lake Kawana (near Nicklin Way). The associated discharge to the head of Tokara Canal should also assist by providing additional "flushing" to the end of the canal. It is not expected that the operation of this pump will be continuous (more likely to operate for about 12 hours a day), but these details will be finalised when the size of the lake in the "Kawana Beach" development is known.

This pumping system has nothing to do with any flood mitigation strategy for the lake and is not designed, or intended, to lower lake water level. The pump installed has a capacity of about 270 litres/second (significantly less than the 1800 litres/second capacity of the tidal exchange pump which pumps from the Mooloolah River to the northern end of Lake Kawana).

9.2 Options for Enhancement of the Inter-connections

Considerable community concern over the impact of the connection to Lake Kawana has been identified previously and during the course of this study. The general view is that there would be a deterioration in water quality and a change in the overall behaviour of the lake as it became more consistently open under the influence of the net pumped discharge. A particular view expressed by a key stakeholder was that there should be capacity to modify the weir height to restrict the flow from Lake Kawana if required. Such a modification was considered to be technically feasible using hydraulically or electrically powered gates installed on the top of the existing weir structure. It was originally proposed that a reasonably detailed cost-benefit analysis be undertaken as a task in this study. As will be set out in the following section, this has not been undertaken.

As an outcome of the various discussions held during this study another option was considered to be more feasible which is to be able to change the pumped discharge rate by modification of the pumping facility.

9.3 Discussion of Options

Weir modification
The rationale for this option is be able to change the height of the weir at various times so that the quantity of exchange between the Lakes can be reduced, thereby allowing Lake Currimundi to maintain its predominantly closed characteristics. The interest in doing this seems to originate from a view that the quality of the Lake ecosystem had deteriorated since the temporary weir inter-connection was made.

This option was considered early in the project by the Expert Panel, which was of the view that the benefits of having a forced exchange, and hence flushing capability would out weigh any negative outcome of the interconnection. This view was based on experience with ICOLLs in NSW where the low level of flushing in many of these systems was the primary cause of poor water quality. It was the view of the Expert panel that no further investigation of structural options be considered until the complete water quality analysis was completed.

With regard to the results shown in Chapter 4 and 5 it is clear that at the current level of development in the Kawana Estates, there are benefits for water quality of having the pumped discharge from the Mooloolah River. As the number of dwellings increase, the water quality in Lake Kawana can be expected to decrease due to the increasing urban run-off. However even under these conditions the general health of Lake Currimundi would not be greatly impacted because of the high flushing capacity in the system during high tides and during opening events.

Although the cost of implementing a variable height weir system has not been estimated, it is anticipated that it would be considerable. This however, is not the primary reason for discounting variable height weir as an option. The principal difficulty is that unless the pumping from the Mooloolah River was stopped, the water level in Lake Kawana would increase risking overtopping of the already low-set revetments. The design and approvals for Lake Kawana require a satisfactory turnover of the Lake water, and consequently water quality problems could be expected during periods of stagnancy in the Lake (ie if the weir was raised and the pumps stopped). If the pumps were allowed to continue to run, the weir would need to be lowered at some stage to release water before overtopping occurred. Such as discrete release would no doubt increase the flow through the main channel of Lake Currimundi potentially increasing bank scour. Of course this could be minimised if the lowering of the weir was timed with a spring tide thereby reducing the head difference across the weir and hence the localised increase in scour velocity immediately in the vicinity of the weir.

Increased Pumped Discharge

As the general view of the project team and Expert Panel is that water quality will benefit from the regular pumped discharge from the Mooloolah River, there may be an advantage in examining an option of increasing the pumping capacity so that a higher net flow results. This would have the advantage of establishing conditions more conducive to natural entrance opening, and hence minimise the need for artificial opening. On the down-side there would need to be a re-examination of the design of the weir to ensure that the Lake Kawana design conditions are maintained. It would also be possible that the increase in average outgoing flow would increase persistent bank scour, but this is not considered likely.

Tokara Canal Inter-connection

The proposed use of a stormwater pipeline to pump from Lake Kawana into the end of Tokara canal will be effective in flushing the canal which is shown from the water quality data and the hydrodynamic modelling to be poorly flushed at present. There will need to be a process of community engagement during the early stage of this connection, as concerns have already been raised about “dirty water” during storms, and turbidity may increase once the Lake Kawana water is released into the confirmed area of the canal. The impact of this option could be modelled using the hydrodynamic model.

As with the main pumped discharge, the quality of water introduced into Lake Currimundi will ultimately depend on the Mooloolah River quality and the level of source control applied to properties within the Lake Kawana development.

9.4 Recommendations

It is recommended that no further consideration be given to modification of the weir. The connection to Tokara canal is considered to be of benefit to the improvement of flushing of the upper end of the canal, but should be monitored specifically to address community concerns over high turbidity levels.

Overall the main recommendation is that water quality parameters need to be monitored regularly in Lake Kawana to assess any change resulting from the development. Ultimately, once the management of the development transfers to SCRC, the only effective means of managing water quality in Lake Kawana/Lake Currimundi system will be catchment runoff management and pollutant source control.

CHAPTER 10 - ADAPTIVE MANAGEMENT FRAMEWORK

10.1 BACKGROUND INFORMATION

Adaptive management frameworks (AMF) have been highlighted as an approach that is well-suited to managing natural resources and environments (Leach et al. 2006). Typically this management occurs in the context of a range of stakeholders who have multiple social, economic and environmental values and aspirations and where the natural processes are inherently non-linear, dynamic (time-varying) with spatial dependency and occur at a large range of scales.

> *"Adaptive management is now recognised internationally as a systematic way to continually improve management policies and practices by learning from the outcomes of operational programs (learning by doing)."*
>
> Leach et al. (2006)

There are six basic components of an AMF that have been identified and promoted to improve planning and decision-making in Australia's coastal zone (Leach et al. 2006):

1. **Information Collation -** information from stakeholders and ongoing research is pooled and organised so it can be readily accessed and used to improve common understanding of management issues and opportunities.

2. **Systems analysis and vision -** stakeholders come together to develop their management vision and aspirations for a particular location, catchment or region and develop a systems approach to their assets to enable differing perspectives, values and beliefs and linkages between understandings to be explored. Concepts are refined to provide a workable understanding of the ecological system and its expected responses.

3. **Plan making -** stakeholders collectively establish management goals and targets and negotiate a preferred strategy based on consideration of multiple and sometimes conflicting objectives and possible trade-offs that may be required.

4. **Implementing actions -** stakeholders assign roles, responsibilities and resources to conduct the agreed actions for achieving goals and targets in the plan.

5. **Monitoring and reviewing -** stakeholders evaluate progress towards the vision, goals and implementation schedule and targets established at the start of the adaptive management process, and modify goals or practices as a result of emerging knowledge, using agreed review timelines.

6. **Core components -** Comprise the facilitation and management of the adaptive management process and the evolving knowledge where networking, learning, negotiation, conflict resolution and knowledge development processes are organised and facilitated among NRM

stakeholders to ensure the adaptive management processes are effective and efficient in achieving the proposed outcomes.

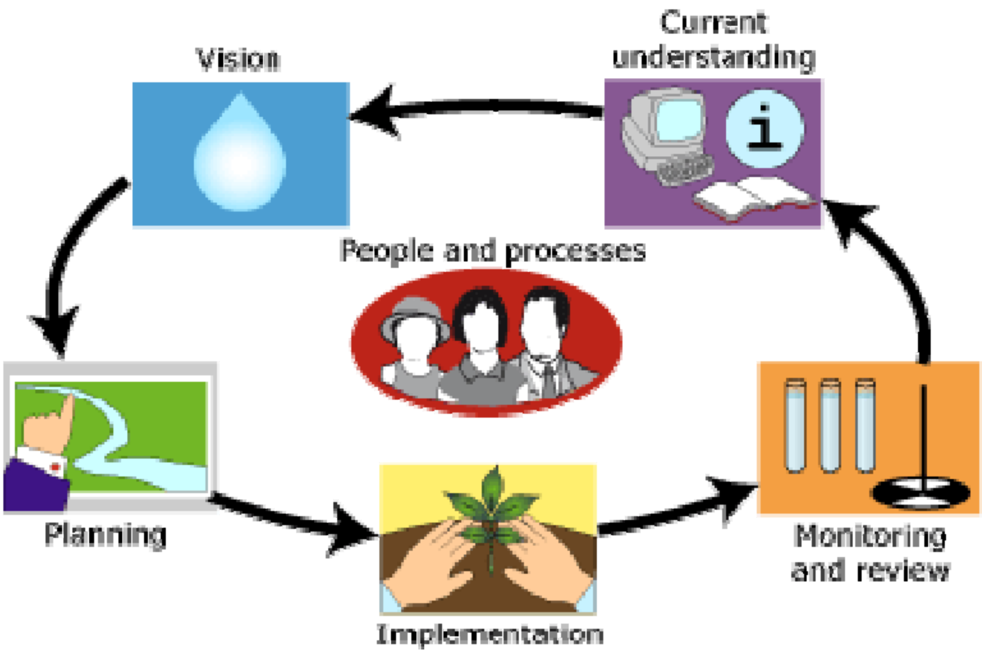

Figure 61: Adaptive management framework highlighting the key components involved (Leach et al. 2006)

10.2 ADAPTIVE MANAGEMENT FRAMEWORK – LAKE CURRIMUNDI

Integration of this updated knowledge and understanding depends on the following components:

- Protocol or guideline for management
- An effective monitoring program
- The capacity to model or simulate system response to proposed action
- A workable cost-effective suite of management options
- A decision making process that engages key stakeholders
- A commitment to continue adapting

10.3 MANAGEMENT PROTOCOLS - ADVANCEMENT OF THE LEROMP

The development and application of the *Lake and Estuary Risk and Operational Management Protocols* (LEROMP) for the lakes including Lake Currimundi provides the basis of an enabled adaptive management framework. It cites a holistic and inclusive approach with clear vision and plans. Furthermore, the systematic communication and negotiation that has occurred between the Caloundra City Council, community members and research institutions (e.g. community workshops, Lake Currimundi Dynamics Study) is closely aligned with the core AMF component of ‘people and processes’, which underpins each step of the AMF.

A key outcome of the Lake Currimundi Dynamics study is the advancement of the LEROMP through the advancement of the current understanding of the important physical processes and water quality dynamics that are occurring in this system. This updated knowledge should be used to refine the management (including treatment options) of the Lake. The LEROMP is quite an extensive document, and it is not within the scope of this project to examine all of its content. What follows, however, sets out a number of specific examples of the integration of the outputs of the Dynamics Study into the LEROMP, to be used as a guide for subsequent adaptive action. These examples are organised into the five main themes of adaptive management as set out in Section 10.2.

10.3.1 Enhancing the Monitoring Program

In accordance with the broad objectives of proactive treatment T3 (Monitor water quality of Currimundi Lake), this study has provided a significant improvement in the current understanding and knowledge of the water quality dynamics within this system and in turn, this facilitates a more strategic approach to monitoring.

Overall, this study has identified eight water quality recommendations (refer Chapter 11), which would improve the efficacy of the water quality monitoring and management of this system.

Integrated monitoring between Caloundra City Council and CCCG

Recommendations 1-4, 7 broadly define the framework for integrated monitoring between the SCRC and the CCCG for Lake Currimundi and apportions responsibilities for each group. Successful implementation of these recommendations within the LEROMP will depend on the adoption of a consistent and robust water quality monitoring program by all participants. These specific recommendations require effective communication between all stakeholders as well as meaningful expert advice regarding best collection locations and techniques, standardising monitoring times/dates, validation of data, procedures, storage and communication of data.

For example, it was identified in this study that the existing water quality monitoring in Lake Currimundi was not standardised against the tidal flow and was not carried out on a consistent frequency (sampling frequency). Such inconsistency is known to introduce variability in the data that is difficult to account for and therefore reduce the efficacy of the data to be used to monitor water quality.

It is also important that the Quality Assurance/Quality Control (QA/QC) protocols incorporated within the water quality monitoring program are best practice and that all participants in the monitoring program are aware of these protocols, are aware of their importance in maintaining the integrity of the monitoring samples and adhere to their requirements. These protocols should include, but not be limited to, calibration procedures, minimising contamination of samples, sample preservation, utilisation of field and laboratory blanks and duplicate samples.

Updated monitoring program to include chlorophyll-a, and coincident environmental parameters

This study has highlighted the need to include chlorophyll-*a* in the monitoring program. Currently, the Reactive Treatment for water quality for the Lake predominantly rely on the occurrence of anoxic conditions (depleted oxygen) to trigger appropriate responses. Specifically, the application of ICOLL Entrance Management Action Keys CMDA1.1, CMDA1.2, CMDA1.3 and CMDA1.4 detail the actions for anoxic water quality for various risk events. CMDA1.1 relates to the threat of ingress of algae into the Currimundi Lake while CMDA1.2-1.4 relate to anoxic water quality conditions within the Lake itself.

Importantly, Management Action Key CMDA 1.3 specifically relates to the occurrence of eutrophication (algal blooms) within the Lake, but relies on anoxic conditions to trigger this. However, the current understanding of the dynamics of DO in the Lake system based on the monitoring programs carried out by CCC, CCCG and SCU highlight the following:

- CCC water quality monitoring currently indicates that anoxic conditions are yet to be recorded in the Lake while the community monitoring has recorded only a small amount of instances of depleted DO, most notably in 2004 and 2006
- DO levels exhibit strong spatial gradients in the Lake, particularly at the ends of canals (monitoring sites 3, 5 and 6) with lower DO levels at depth.
- The system mixing is faster at depth than at the surface and/or locations closer to the entrance than upstream.

The most pertinent observation is that anoxic conditions have been rarely observed in the Lake.

A more relevant and practical measure of algal levels is chlorophyll-*a*, which is a commonly-used indicator of ecosystem health and provides a direct measure of algal biomass. Consequently, these reactive treatments should consider chlorophyll-*a* concentrations in addition to DO when evaluating the management action keys. Furthermore, monitoring for anoxic conditions and chlorophyll-*a* need to be undertaken throughout the water column with particular emphasis placed on ‘upstream’ locations where tidal flushing is limited.

If anoxic /high chlorophyll-*a* levels are observed then monitoring should be conducted daily to ensure that improved water quality conditions return in response to the management actions that are undertaken.

Finally, these actions need to be evaluated based on both baseline and event-based monitoring and include coincident rainfall levels in the catchment.

Event–based monitoring

A significant outcome of this study was the recommendation of event-based monitoring (Council-based) to compliment the ‘baseline’ monitoring for the Lake (Recommendation 4).

It has been clearly shown in this study that the water quality of the Lake Currimundi system (including Lake Kawana) is at times highly dynamic and sensitive to catchment inputs and entrance conditions and that these dynamics vary both spatially and temporally throughout the system. Consequently, baseline monitoring is unlikely to adequately capture these dynamics.

The intensive monitoring program that was carried out in June 2008 provided an excellent opportunity to evaluate the utility of event-based monitoring as well as advance knowledge of the complex nutrient-algae dynamics occurring in Lake Currimundi within the context of a widened entrance and a large rainfall event

(>160mm). Under this context, this monitoring highlighted the relative importance of the following:

- catchment rainfall as a mechanism of contaminant transport into the Lake,
- effect of distance from the contaminant source on the nutrient-algal dynamics,
- effect of distance from the oceanic-flushed entrance on water quality,
- effect of depth within the water column on water quality,
- effect of time elapsed since the entrance was opened.

To further examine these dynamics, event analysis relating the large rainfall that occurred on the 2nd of June to the nutrient-chlorophyll-*a* dynamics for monitoring sites 1, 4 and 6 (Figure 62) are presented in Figures 63-65.

Site 6 is located furthest from the entrance of Lake Currimundi of all the monitoring sites. The data (Figure 63) shows that at the beginning of the monitoring period, nitrate was at its highest indicating an immediate increase in this form of nitrogen in response to the large rainfall event that occurred on the 2nd of June. Approximately 5-6 days after the rainfall event, nitrate concentration decreased and chlorophyll-*a* measured at 1.0 metre increased indicating that algal growth in the upper water column depleted the nitrate pool. A spike in the ammonia approximately 12 days after the rainfall event and 4 days after the first chlorophyll-*a* spike may reflect the remineralisation of algal die-off and/or particulate organic matter flushed into the lake during the initial rainfall event. Finally, there is a uniform increase in chlorophyll-*a* throughout the water column 20 days after the rainfall event, most likely triggered by the elevated nitrate and ammonia concentrations in the system.

Figure 62: Monitoring locations used during the intensive program, June 2008.

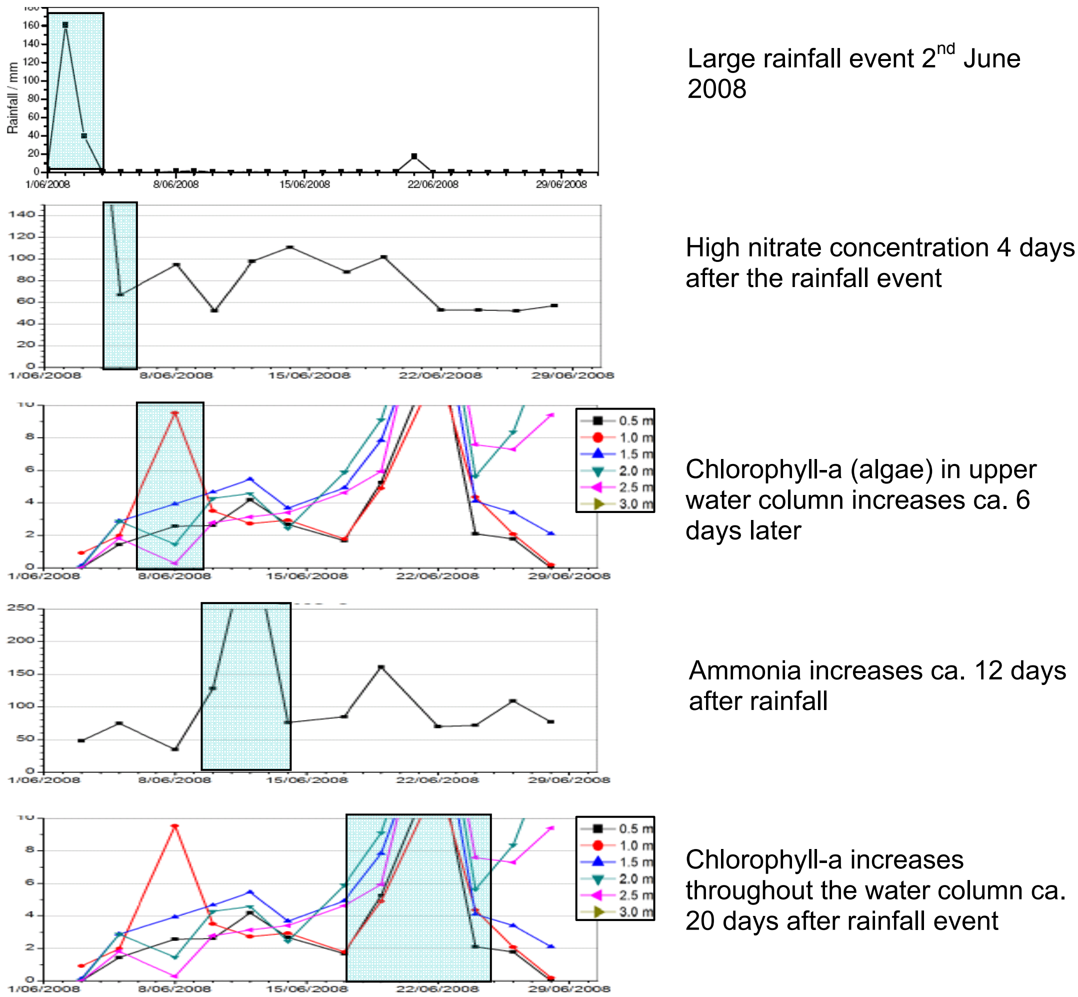

Figure 63: Event analysis for monitoring location 6 showing the dynamic relationship between rainfall, algae (as chlorophyll-*a*) and nutrients (nitrate and ammonia)

A similar pattern (to Site 6) is observed for Site 4 (Figure 64) with the rainfall event followed by increased nitrate and chlorophyll-*a*, then increased ammonia and then a secondary (and larger) increase in chlorophyll-*a*. The same mechanisms that were highlighted for Site 6 will be at play here although tidal effects are also likely to influence.

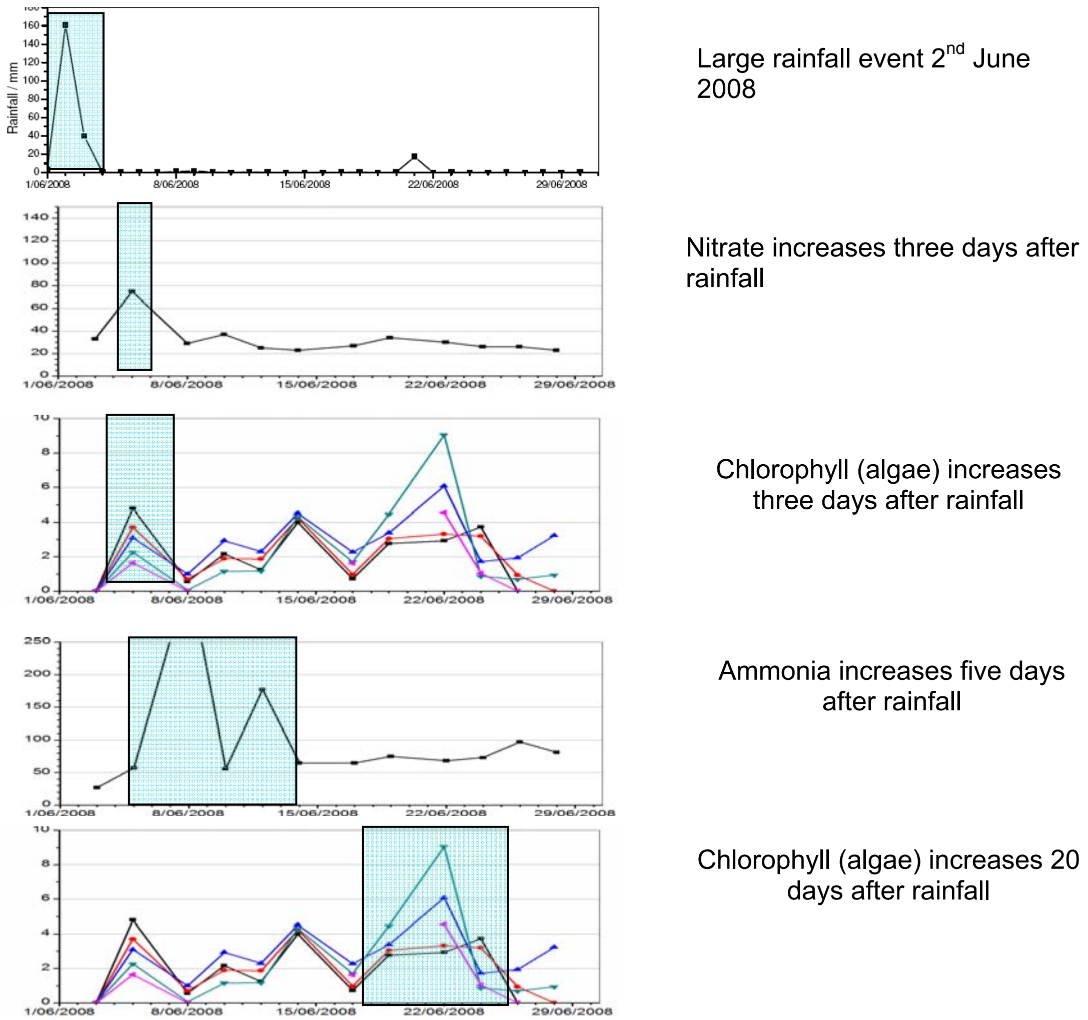

Figure 64: Event analysis for monitoring location 4 showing the dynamic relationship between rainfall, algae (as chlorophyll-*a*) and nutrients (nitrate and ammonia) Event analysis – monitoring location 4

At the entrance of the Lake, there is still a similar set of interrelationships between rainfall, nutrients and algae (Figure 65), however this site is strongly influenced by tidal flows and also the increased distance from the catchment inflow. Subsequently, spikes in nitrate, ammonia and chlorophyll-*a* occur later than at sites 4 and 6.

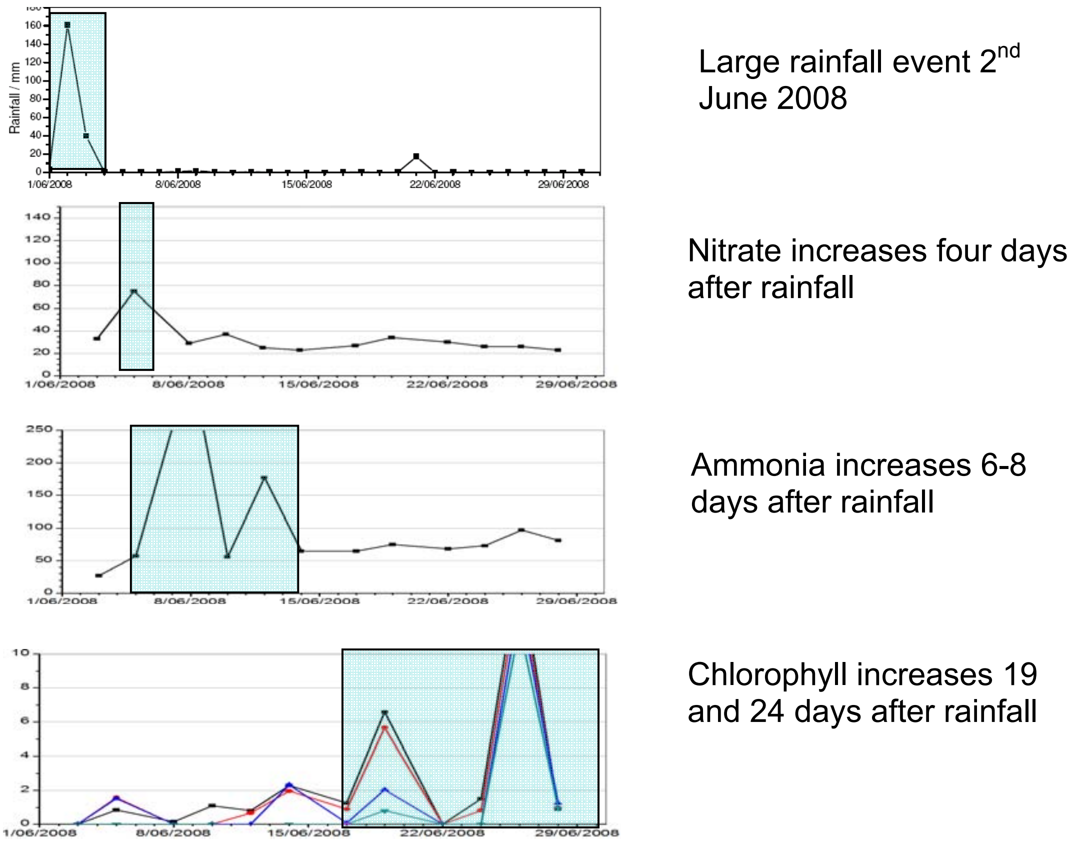

Figure 65: Event analysis for monitoring location 6 showing the dynamic relationship between rainfall, algae (as chlorophyll-*a*) and nutrients (nitrate and ammonia)

Integration of Event-Based Monitoring

The integration of event-based monitoring within the LEROMP falls neatly within the objectives of Proactive Treatment 3 (Monitor Water Quality), specifically to develop and perform strategic water quality processes and trends. Event-based monitoring also compliments the objectives of Proactive Treatment 1 (*Develop opening and closing protocols for Caloundra's ICOLLs*) and Proactive Treatment 2 (*Investigate and consider implications on Lake system associated with mechanical breach of entrance berm prior to commencing work*).

As per Recommendation 4 (refer Chapter 11), Council-based water quality effort should be directed towards event monitoring with intensive monitoring prior to and after planned entrance opening and closing. It is further recommended that the monitoring program detailed in the intensive monitoring program (refer Chapter 5) be used as a template for this event-based monitoring including site-selection and the water quality indicators that are measured.

- Monitoring to preferably include nitrogen components, chlorophyll-*a*, DO, salinity, turbidity, temperature and faecal coliform counts as well as coincident environmental parameters.
- Daily monitoring at seven sites for a minimum of 3 days prior to planned opening / closing to provide baseline conditions.
- Daily monitoring at seven sites for a minimum of 7 days after planned opening / closing. Extension of the monitoring period if water quality indicators show that the system is reacting differently than from expected (as based on the

findings of this study). For example, if available water quality data do not show 'improvement' after the entrance has been opened for up to 7 days.

Integrated monitoring of Lake Currimundi and Lake Kawana

Recommendations R5-R8 highlight the importance of a more holistic approach to managing and evaluating water quality within Lake Currimundi. Specifically, this study has confirmed the utility of introducing inflow from Lake Kawana into Lake Currimundi as a water quality management option. This was explicitly tested in the generalised additive modelling (GAM) assessment of Caloundra City Council's dataset (refer Chapter 6) and clearly showed a reducing effect on faecal coliform counts, and to a lesser extent, the dissolved inorganic nitrogen (DIN) concentrations, within the Lake.

Within the AMF, this exemplifies the stages of implementation (introducing Lake Kawana inflow), monitoring (CCC monitoring) and reviewing (Chapter 5-6), and increased current understanding (Chapter 5-6). Consequently, recommendations R5-R8 reflect a modified vision for the water quality in the Lake, and improved planning.

10.3.2 Capacity to Model or Simulate System Response to Proposed Action

As per Recommendation 22 (Chapter 11), there should be a commitment to establishing a suite of conceptual, empirical and computational models that can be used to compliment the management of the Lake.

The capacity to understand and predict ('models for prediction') how the biogeochemical, geomorphological and hydrodynamic characteristics of the Lake will respond to proposed management actions under different ambient conditions enables the risks (and benefits) of various management scenarios to be evaluated and has application to the following treatments:

- Proactive Treatment T1 - opening/closing protocols
- Proactive Treatment T2 - implications of mechanical breach of the entrance
- Proactive Treatment T3 - developing and performing strategic water quality monitoring
- Proactive Treatment T4 - avoiding unnecessary dredging and excavations
- Proactive Treatment T5 - developing an effective Catchment Management Action Plan for the Lake
- Proactive Treatment T11 - Developing a Toxic Spill response plan

Models for Understanding

Typically, conceptual models, empirical models and basic process-based models (e.g. STELLA-type) are more applicable at the stages of 'Current Understanding' and 'Vision and Systems Analysis', where a qualitative/semi-quantitative understanding of the system (or elements of the system) is required (i.e. 'models for learning'). In particular, these low-level and mid-level models can typically incorporate both tacit and formalised knowledge, highlight current knowledge (and knowledge gaps) and provide a framework for the inclusion of stakeholders that do not have a modelling background.

These class of models can also have good utility in the 'Monitoring and Reviewing' stage of the AMF. The generalized additive modelling (GAM) described in Chapter 6 is an example of enhancing current understanding of the coliform and nitrogen dynamics in the Lake in the context of catchment rainfall, entrance opening and Lake Kawana inflow.

Models for Prediction

More numerically-intense models such as used here for the hydrodynamic modelling are suited to scenario testing and therefore relate to the Plan Making stage of the AMF.

For example, current knowledge of Lake Currimundi dynamics includes that Lake Kawana generally reduces flood flow velocities and infilling at the entrance except during very high spring tides or following entrance opening when it facilitates increased flow velocities and increased infilling. The timing of mechanical opening of the entrance as a water quality mitigation option would take into account the increased 'flushing' of the system achieved under certain conditions (i.e. spring tide).

As per Recommendation 13 (Chapter 11), implementation of modelling capacity within the LEROMP is achievable through conducting hydrodynamic modelling for future events to build a matrix of calibrated outputs. This matrix would provide a readily accessible index of the generic response of the system to mechanical openings under different conditions.

10.3.3 Workable Cost-Effective Suite of Management Options

This study highlights that the current strategy of artificially opening and closing the Lake to be a cost-effective, efficient and flexible method of achieving water quality and other environmental objectives.

This is consistent with the objective of Proactive Treatment T1 (Develop Opening and Closing Protocols for Caloundra's ICOLLs), which seeks to develop a set of sustainable and cost effective protocols for determining and implementing management options for the entrance of the Lake. It also highlights the utility and efficacy of the 'monitoring and evaluation' stage of the AMF, which guides further management options.

Prescribed 'Trigger' levels for mechanical opening

This study has highlighted that mechanical opening of the entrance should be limited to the prevention of flooding with the maintenance of a prescribed maximum water level in the lake which is compatible with foreshore amenity and midge control (Recommendation 23).

The determination of a prescribed maximum water level (threshold) is based on current understanding and vision for the Lake within the context of an AMF. Considerations for determining this maximum water level should include, but not necessarily be restricted to, the following:

- That current understanding be used to guide the determination of the threshold value. For example, it is known that at 0.9m AHD, bank instability has historically been observed in the Lake and the design freeboard in Lake Kawana is reached.
- That determination of this threshold should be collectively achieved by the stakeholders.

- That there is recognition that such thresholds are ICOLL-dependent. Furthermore, these thresholds might also be seasonally-dependent, reflecting the temporal changes in hydrologic cycles. For example, a New Zealand ICOLL (Lake Ellesmere) utilises a threshold of 1.05m above mean sea level (a.s.l.) for the period August-March and 1.13m a.s.l. for March-August (Schallenberg et al. *in press*).
- That the efficacy of the prescribed level be evaluated and if necessary, updated to reflect updated knowledge, vision and aspirations.

10.3.4 Decision Making Process Engaging key Stakeholders

As is discussed in the summary and recommendations (Chapter 11), a key component of the AMF is open engagement and involvement of the community in the decision making process. There are strong benefits from including all stakeholders (or representatives thereof in) in the management process as it invariably creates a sense of ownership and empowerment, and fosters trust between stakeholder groups.

The most obvious step in integrating greater stakeholder in the LEROMP is to integrate the community-based monitoring with the council monitoring, as has been highlighted already.

It is recommended that a community steering group be empowered to support Council's decision-making processes in terms of lake and entrance management (see Recommendation 24).

10.3.5 Commitment to Continue Adaptive Management

Under the broad definition of an AMF, there needs to be an on-going commitment to developing the management of Lake Currimundi through continued monitoring and modelling, flexibility in management operations, reliance on community involvement and more active engagement of the expertise within SCRC in the determination of relationships and management responses.

CHAPTER 11 - SUMMARY OF FINDINGS AND RECOMMENDATIONS

The Lake Currimundi Dynamics Study has 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.

In this chapter the key findings and recommendations of the study components will be summarized, interrelationships discussed and recommendations for future management presented. The key findings are grouped in terms of water quality, bank erosion, biting midge and tidal hydrodynamics and entrance behaviour. The interrelationships and monitoring requirements are discussed in terms of the AMF, and the key recommendations will be set out where appropriate.

11.1 Water Quality

The study brought together some ad hoc measurements and observations about water quality; an analysis of both the 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, leading to the following recommendation.

Recommendation 1:
Integrate the water quality monitoring program undertaken by the Currimundi Catchment Care Group into the overall monitoring for the adaptive management framework.

In this regard the community groups should seek expert advice regarding best collection locations, standardise monitoring times/dates, validation of data, procedures, storage and communication of data.

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:

Dissolved Inorganic Nitrogen:

1. The annual trend in DIN indicates potential combined 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.
5. Monthly cumulative rainfall levels above ca. 100mm appear to lead to decreased DIN, most likely to trigger primary production leading to nutrient depletion and/or dilution effect.

Faecal coliform count:

6. There is strong indication that the introduction of the Lake Kawana inflow into Lake Currimundi in 2005 has been effective in decreasing coliform counts despite there being an increasing annual trend in coliform.
7. Oceanic flushing occurring, but probably mainly for sites nearer the entrance (as indicated by conductivity).

Chlorophyll-*a*:

8. Chlorophyll-*a* concentrations in Lake Kawana appear to be significantly influenced by large rainfall events. The large event on 2nd June 2008 resulted in a rapid increase in chlorophyll-*a* for the following five days, followed by a lull for the next 10 days and a secondary increase in chlorophyll-*a* for the subsequent three days. The secondary peak in chlorophyll-*a* is thought to result from nutrient cycling.
9. Smaller rainfall events appear to have minimal influence on chlorophyll-*a*, probably due to insufficient nutrients to trigger primary production.
10. There is evidence that there is a site-dependency on the chlorophyll-*a*, with higher chlorophyll-*a* observed further from the entrance. However, this spatial effect is strongly biased by Site 3

As an outcome of this analysis (and cognisant of the fact that the data only reflect conditions over a limited period of time) the following recommendations are made.

Recommendation 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.

Recommendation 3:
Encourage and support community-based water quality monitoring if appropriate to provide baseline information.

Recommendation 4:
Direct Council-based water quality effort towards event monitoring with intensive monitoring prior to and after planned entrance opening and closing activities..

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.

Recommendation 5:
Undertake no structural modification to Lake Kawana Weir.

Recommendation 6:
Proceed with the proposed inter-connection to the end of Tokara Canal.

Recommendation 7:
Direct routine monitoring of water quality throughout the system to defining the changes in water quality which may occur as a result of increasing urban development in the catchment.

Recommendation 8:
Incorporate the inter-connectedness of the Kawana and Currimundi systems into environmental management and planning.

11.2 Bank erosion

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

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.

There are two key recommendations that come from the overall assessment of bank erosion. 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. The recommendations are:

Recommendation 9:
Develop a lake foreshore erosion management plan including riparian vegetation rehabilitation and structural bank stabilisation where appropriate.

In the development of this plan the recommendations for midge control should be taken into account. These include the need for steeper banks and minimisation of exposed tidal flats. 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. 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.

Recommendation 10:
Develop and implement a boat wash management strategy

11.3 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.

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 bitting midge at Lake Currimundi.

Recommendation 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.

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.

Recommendation 12:
Limit lake-side beach elevation to less than 0.6m AHD.

Any proposals that increases the tidal range and as a consequence increase the intertidal beach larval habitat should be avoided.

11.4 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 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.

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. However, once a representative number of events are monitored and modelled it will be appropriate to develop simple approximations of tidal response to a given quantity of sand removed (and consequently a particular entrance channel configuration). It would be expected that entrance opening will always be timed for a spring tide, and for a maximum lake level. Once the entrance has broken through, the channel will develop to a particular configuration, and will gradually infill. 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.

Recommendation 13:
Undertake hydrodynamic monitoring and modelling for future events to build a matrix of calibrated outputs for inclusion in the AMF.

Recommendation 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.

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.

Recommendation 15:
Establish a remote camera system for entrance channel monitoring.

This system can be integrated in with beach condition monitoring and beach safety management utilising a camera located at the Lifeguard tower.

Recommendation 16:
Limit the migration of the entrance channel to the northern half of the lake mouth through a berm management program.

Recommendation 17:
Maintain a berm height of 2m above spring high tide level, and a width of 50m at that level.

11.5 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

11.5.1 AMF Protocol

As discussed in Chapter 10, the Lake and Estuary Risk and Operational Management Protocol (LEROMP) is a document prepared by Council officers some time ago. The LEROMP 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. Examples of how new understanding of lake dynamic responses in the Lake can be integrated is given in Chapter 10.

Recommendation 18:
Enhance the adaptive management framework (AMF) approach currently being used.

Recommendation 19:
Use SCRC's Lake and Estuary Risk and Operational Management Protocol (LEROMP) as the foundation for subsequent adaptive responses.

11.5.2 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. An implementation plan for monitoring is presented in Appendix 11. The key elements of this are summarised as follows:

- 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.

Recommendation 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.

Recommendation 21:
A central database should be established 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.

11.5.3 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. An implementation plan for integrating modelling and monitoring is presented in Appendix 11.

Recommendation 22:
Ensure that data is not only collected but analysed with the aim of establishing a range of conceptual, empirical and computational models.

11.5.4 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.

Recommendation 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.

11.5.5 Decision Making

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.

Recommendation 24:
Empower a community steering group to support Council's decision making processes in terms of lake and entrance management.

11.5.6 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.

Recommendation 25:
Commit Council resources and provide a mandate for SCRC officers to implement the AMF thereby ensuring its success.

11.6 Other Issues

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.

Recommendation 26:
Implement a catchment-wide pollutant source control program to limit the impact of urbanisation.

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. Geotechnical surveys of the dunal area immediately adjacent to the Watson Street road reserve should be undertaken as part of this asset protection strategy development.

Recommendation 27:
Undertake a Shoreline Erosion Management Plan including entrance stability options

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.

Recommendation 28:
Develop a strategy for engagement with the community leading to a climate change adaptation strategy.

REFERENCES

1. Butterworth, V. (2005) Biting Midge Control Currimundi CCC Agenda Report, Caloundra City Council.

2. Caloundra City Council (2006) Lake and Estuary Risk and Operational Management Protocols (LEROMP)

3. Cardno & Davies (1998) Kawana Waters Master Plan Impact Assessment Birtinya

4. Castelle, B. (2006) Morphological Study of the Mouth of Tallebudgera and Currumbin Creeks – DEFLT 3D Modelling, Griffith Centre for Coastal Management Research Report No. 52.

5. Costanzo, S., Schlacher, T., Liddell, B., Longstaff, B., Levy, D. and Udy, J. (2002) Ecosystem Health of Currimundi Lake: Pilot Assessment & Regional Integration, Report to Caloundra City Council by University of Sunshine Coast and University of Queensland

6. Hekel, H. and Day, R.W. (1976) Quaternary Geology of the Sunshine Coast Southeast Queensland Study for the BPA

7. Helman, P. and Tomlinson, R.B. (2008), Coastal Storms and Climate Change Over the Last Two Centuries, East Coast Australia", Solutions to Coastal Disasters 2008, Eds. Wallendorf, L., Ewing, L., Jones, C. and Jaffe, B., ASCE, pp. 139-146.

8. Ihaka, R. and R. Gentleman: A language for data analysis and graphics. Journal of Computational and Graphical Statistics, 5(3):299-314, 1996

9. Leach, G., Bennett, J., Shaw, R., Lawrence, P., Thomsen, D., Cox, M. and Long, P. (2006). Enabling adaptive management for regional natural resource management. August 2006. Technical Report 81. Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management (Coastal CRC)

10. Leggett, R. (1997) Fish, Invertebrate and Aquatic Plant Survey of Currimundi Lake Drainage. Report for Caloundra City Council

11. Leggett, R. (2000) Fish, Invertebrate and Aquatic Plant Survey of Currimundi Lake Drainage. Report for Lensworth Kawana Waters Pty Ltd

12. Lennard, M (2006) Pers Comm

13. O'Connell, D. and Wiltshire, G. (2005) The Mysteries of Closed Coastal lakes – "Myths Busted", 14th NSW Coastal Conference, Narooma, November

14. Robertson, A., Kirkpatrick, S. and Mondon, E. (2007), Saltwater Creek Foreshore Master Plan, Griffith Centre for Coastal Management Research Report No. 53.

15. Robertson, A. Teasdale, P., Burns, P. Connolly, R. and Tomlinson, R.B. (2006), Saltwater Creek Environmental Inventory. Griffith Centre for Coastal Management Research Report No. 6.

16. SKM (2002) Mooloolah River – Currimundi Canal Floodplain. Flood Study and Stormwater Management Plan

17. Steffen, W. (2009) Climate Change Science – Faster Change and More Serious Risks, Australian Government Dept of Climate Change

18. Tomlinson, R.B. (2006) Lake Currimundi Dynamics, report to Caloundra City Council, December.

19. WBM (2000) Currimundi Lake Entrance Opening and Water Quality Management Options

20. Weir, F., Hughes, M. and Baldock, T. (2006), Beach Face and Berm Morphodynamics Fronting a Coastal lagoon, Jnl Geomorphology, Vol. 82 Issue 3-4, pp.331-346.

21. Wilkes, K. (1995) Currimundi Lake Opening Management Strategy MengSc Thesis QUT

22. Witheridge, G. (2006) Currimundi Lake Erosion, Report by Catchments and Creeks Pty Ltd.

23. Wood, S. (2006). Generalized Additive Models. An Introduction with R. Chapman and Hall/CRC. Boca Raton.

24. Wood, S. (2008).The mgcv Package. Available at: http://cran.r-project.org/web/packages/mgcv/mgcv.pdf accessed 1 October 2008