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WATTLE RANGE COUNCIL

Lake George

Study

301015-03541 – 002

26 Oct 2015

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WATTLE RANGE COUNCIL
LAKE GEORGE
STUDY

SYNOPSIS

This report identifies the estuarine processes and management issues at Lake George and presents a management scheme that has the objective of improving the ecology and recreational amenity of the Lake system.

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PROJECT 301015-03541 - LAKE GEORGE

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EXECUTIVE SUMMARY

Lake George is a large estuarine lake system of three inter-connected water bodies situated in the south-east of South Australia, these being the Big (or northern) Lake, the Middle Lake and Southern (or "little") Lake. Historically, the Lake was a land-locked body of water fed by rainfall and freshwater springs, with these sources of water still important in the overall hydrological balance of the Lake. Within the last century, anthropogenic changes have occurred at the Lake which have altered the lake ecology. In particular, the two main changes include:

- The cutting of a channel connecting the Southern Lake to the sea at Beachport in the early 20th Century, which has allowed seawater ingress into the Lake and sand transport up into the Lake from Rivoli Bay, depositing onto a large flood tide delta; and
- The construction of a series of channels in the catchment area of the Lake, leading to the drainage of freshwater and agricultural runoff directly into Lake George via Drain M, also into the southern basin of the Lake.

These two major changes have led to a major change in the lake ecology over time. Despite these two major disturbances to the ecology and hydrology of the Lake, until the late 1990's the Lake sustained a healthy ecology. Since the late 1990's the ecology of the Lake has degraded significantly, triggered by the following hydrological factors:

- a series of years of deficient rainfall resulting in negligible inflow from Drain M;
- the blockage of the outlet to the sea by marine sand, preventing interaction between the Lake and the sea, which has been known to occur since construction of the lake outlet.

This report documents a study of Lake George through the analysis of existing data, the inflows and outflows, consideration of ecological and recreational values and development of a management scheme to achieve the desirable range of levels for the lake, manage the inflows and outflows and maintain the water quality.

Estuarine Processes

Lake George and Rivoli Bay formed as a result of a breach in the Robe Range as sea levels rose by up to 140 m following the most recent glacial maximum. Due to the sea level rise and breaching of the Robe Range, a saltwater lagoon was formed in what are now lakes Eliza, St Clair and George.

The Lake in its natural state was a land-locked body of water, fed by freshwater springs, rainfall and overland runoff. In its natural state, there was no significant natural connection to the sea. The natural salinity of the Lake would sometimes exceed that of the sea, being hypersaline, due to evaporation and concentration of salinity within the Lake during the hot, dry summer months.

The natural system of Lake George has been modified extensively due to human activity. In particular, the following modifications have had the greatest influence (Hobbs and de Jong, 2009):

- Construction of an outlet channel connecting Lake George to the sea at Beachport (completed in 1914)
- Sutherland's drain, draining the agricultural land to the south-east of Lake George, constructed in 1915
- Drain M, which commenced construction in 1915, and was completed to its present state in 1966.
- Timber logs were used to regulate the outflow through Drain M since the 1980's. Concrete logs were subsequently added to the Lake George outlet in an attempt to prevent sand from moving into the lake (1991).
- Drain M Diversion channel was constructed between Drain M and Middle Lake in 2000
- Works were undertaken to improve the flow path through the flood tide delta at the Lake outlet as well as improve the flow path between Little Lake and Middle Lake in 2006 and 2009. Works have been undertaken to remove sand from the Lake George outlet channel since 2000 and confine the channel to a narrower width.

Impacts on the Lake due to the above changes to the natural system have been extensive and have included:

- Changes to the natural salinity and water balance within the Lake when compared with the natural regime, due to freshwater and nutrient inflows from Drain M and seawater inflows through the Lake connection to the sea;
- Associated changes to the ecology of the Lake, including changes to fish species assemblages, changes to fringing vegetation and benthic algae species as a response to changing salinity ranges and water level fluctuations as well as stocking of the Lake with fish species introduced due to the connection with the sea;
- Growth of a flood tide sand delta within the Little Lake, as a result of sand being transported into the Lake via the outlet channel to Rivoli Bay.

The main freshwater source into Lake George, apart from direct rainfall, is water from the Drain M catchment. The inflow from Drain M is seasonal with the predominant inflows occurring from July to October. Inflows into the Lake from Drain M are highly variable and average annual discharges since the late 1990's have declined. Factors that have led to the decline in freshwater inflow include agricultural practices, particularly plantation forestry in the drainage catchments. There has been limited inflow from the sea into the Lake due to sand frequently blocking the outlet channel connecting Little Lake to Rivoli Bay. The outlet had been excavated of sand several times between 2001 and 2008.

Water Quality and Fishing

A water quality monitoring program of the Lake found the following:

- Lake George has been overwhelmed by nutrients, particularly organic carbon and nitrogen-based compounds;
- Blue-green algae is the dominant phytoplankton assemblage and currently dominates the biomass of the lake;

- The lakes are considered to be hypereutrophic (due to high concentrations of algae and nutrients), turbid and hypersaline, particularly the Big and Middle lakes.

Lake George formerly supported an important inland waters fishery for many years, primarily yellow-eye mullet, which was used by commercial and recreational net fishers (Ye *et al*. 2002). Siltation of the lower lake basin led to a significant reduction in water levels since the early 1990s, with a major fish kill occurring in February 1999. Since April 1999, a moratorium on fishing has been enforced on the lake in an attempt to allow fish stocks to recover from this event. It was assessed that the connection between Lake George and Rivoli Bay was important to allow both young and adult mullet to enter the Lakes (Ye *et al.* 2002). Monitoring of water levels and maintaining an ongoing connection between the lake and the sea as well as freshwater inflows from Drain M were considered to be important factors in maintaining ideal conditions for fish.

Outlet Channel Hydrodynamics

It has been noted in several studies (including Ye *et al* 2002, Hobbs and de Jong, 2009) that the existing ecology of the Lakes is dependent on the connection with the sea, and that this channel has rapidly in-filled with beach sand on many occasions, despite being excavated many times.

To understand the propensity for the channel to fill with sand, despite attempts to excavate it and manage the channel velocities by altering the configuration of the outlet weir, a tidal inlet analysis has been undertaken on the outlet channel connecting Lake George to the sea. The analysis found that the channel geometry when compared with the Lake tidal prism is such that the channel will always tend to silt up, despite attempts to keep it open by managing the outlet regulator and excavating the channel.

Management Issues

Lake George is faced with several management issues, owing to the present multiple uses of the lake and the modification of the lake environment and ecology due to changes in the workings of the natural system.

Management issues experienced at the Lake include:

- **Pressures on the lake ecology** – caused by accumulation of nutrients in the lake system, and a decline in freshwater inflows and inflows from the sea leading to hypersalinity, fish kills and toxic algal blooms;
- **Water level management** – water level target ranges have been set by the Lake George Management Committee to balance recreational usage and ecological values but these have been unable to be achieved due to reduced freshwater and seawater inflows;
- **Recreational values** – allowing access to the Lake environs for a range of recreational activities compatible with the ecology of the lake;
- **Fishing** – whether it is feasible to re-establish recreational and commercial fishing within the lake and what would need to be done to facilitate this.

Stakeholder and Community Consultation

Stakeholder and community consultation was carried out in Beachport in October 2014 and again during March 2015, with the draft report presented and placed on public exhibition.

The stakeholder consultation included:

- One-on-one meetings with key stakeholders including the Lake George Management Committee and Council at Beachport in October 2014;
- Public drop-in information centre attended by Council and WorleyParsons at Beachport in March 2015
- Stakeholder meetings with Council, DPTI, DEWNR SE and SEWCDB in March 2015;
- Public presentations on the Lake George and related Rivoli Bay studies in Beachport in March 2015;
- Hard copies of the report available at the Beachport Visitors Information Centre and on Council website during duration of the exhibition period which covered March 2015;
- Project information posters on display at Beachport Visitors Information Centre during the exhibition period.

A number of submissions were received and these are discussed within the report.

Management Options

Management options have been developed for the Lake relating primarily to the overall objective of improving the ecology and water quality of the Lake George system as well as the Lake recreational values and the economic value of the Lake as a fishery.

It is considered that the water quality and ecology of the Lake can be improved through the following means:

- Improved connectivity of the Lake with Rivoli Bay
- Maintaining the water levels within the target ranges set by the Lake George Management Committee
- Enhancing the supply of fresh water to the Lake system via Drain M and the interconnected drainage network.

The lake outlet management options considered include:

- Modifying the channel configuration to allow the channel to remain open naturally due to scour by tidal flows – this was found to not be feasible;
- Closing the outlet channel to restore the "natural" ecology of the system (i.e. "do nothing") – this was found to be not viable due to reduced freshwater flows into the Lake when compared with historical or "natural" hydrological conditions;

- Management of the outlet weir and groynes to minimise the ingress of sand and allow tidal flows to maintain the water levels in the Lakes to within the target levels specified in the Lake George Management Plan – this option was found to be a viable short-term action to improve the ecology of the Lake, with the longer-term aim of enhancing the freshwater flows into the Lake with a view to restoring the natural ecology.

These options were presented to the community and key stakeholders in March 2015.

Recommended Short Term Management Scheme

The recommended management scheme for the outlet of Lake George is as follows:

1. Dredge the outlet channel to -1 m AHD on the lake side of the outlet regulator.
2. Dredge the outlet channel to -0.5 m AHD on the sea side of the outlet regulator
3. Maintain the logs within the outlet regulator all year round. Maintain the top of the logs at 0.4 m AHD along the full width of the regulator during the winter months. Remove one row of logs to maintain the top of the logs at 0.1 m AHD through the summer months along the entire width of the regulator structure.
4. Maintain the area on the seaward side of the regulator structure at -0.5 m AHD by maintenance dredging as required. This would then reduce the requirement to undertake maintenance dredging in the channel upstream of the regulator structure.

Recommended Long Term Management Scheme

In the longer term, the groynes at the outlet to Lake George could be extended beyond the surf zone - this would reduce the littoral drift transport into the Lake outlet and, therefore, reduce the required frequency of dredging of the channel and slow down the growth of the flood tide delta. It would also allow greater ingress of seawater into the Lake thus improving the ability of the Lake to meet its water level target range. Extending the groynes is a long term capital investment, which would require significant external funding to be provided. As this is the most expensive component of the proposed scheme it could be considered at a later date, following a trial of the short term management scheme above.

In the longer term, limited resources of the various agencies would limit their capacity to commit to ongoing maintenance dredging work in the outlet channel. While a viable connection to the sea may be able to be maintained for some time through implementation of the short-term scheme described above, it will be increasingly difficult in the future to maintain this connection. Efforts to restore freshwater inflow to the Lake from Drain M and the interconnected drainage network should therefore be continued, including restoration of a historical freshwater flow path from Lake Frome to Lake George.

1 INTRODUCTION

Lake George is a large estuarine lake system of three inter-connected water bodies situated in the south-east of South Australia, these being the Big (or northern) Lake, the Middle Lake and Southern (or "little") Lake. The study area is depicted in Figure 1.

Historically, the Lake was a land-locked body of water fed by rainfall and freshwater springs, with these sources of water still important in the overall hydrological balance of the Lake. Within the last century, anthropogenic changes have occurred at the Lake which have altered the lake ecology. In particular, the two main changes include:

- The cutting of a channel connecting the Southern Lake to the sea at Beachport in the early 20th Century, which has allowed seawater ingress into the Lake and sand transport up into the Lake from Rivoli Bay, depositing onto a large flood tide delta; and
- The construction of a series of channels in the catchment area of the Lake, leading to the drainage of freshwater and agricultural runoff directly into Lake George via Drain M, also into the southern basin of the Lake.

These two major changes have led to a major change in the lake ecology over time. Despite these two major disturbances to the ecology and hydrology of the Lake, until the late 1990's the Lake sustained a healthy ecology, the clear water supporting waterbirds, aquatic plants, macro-invertebrates and a thriving recreational fishery (de Jong, 2007). These attributes attracted many visitors to the lake in pursuit of various recreational interests, and in doing so, provided Beachport businesses with valuable year-round tourism income.

According to de Jong (2007), the lake also provided an important regional, national and international ecological function:

- as a refuge for native fish and macro-invertebrates;
- as a destination for waterbirds as regional coastal refuge when local inland wetlands dry out over summer;
- as a refuge for waterbirds from Central and South East Australia when nomadic waterbirds seek drought refuge; and,
- as a key site for migratory waders along the East Asian-Australasian Flyway.

Since the late 1990's the ecology of the Lake has degraded significantly, triggered by the following hydrological factors:

- a series of years of deficient rainfall resulting in negligible inflow from Drain M;
- the blockage of the outlet to the sea by marine sand, preventing interaction between the Lake and the sea, which has been known to occur since construction of the lake outlet.

This report documents a study of the lake levels and water quality of Lake George through the analysis of existing data, the inflows and outflows, consideration of ecological and recreational values and development of a management scheme to achieve the desirable range of levels for the lake, manage the inflows and outflows and maintain the water quality.

Lake George covers an area of nearly 6000 ha and is of high conservation value, being identified as an internationally important site for shorebirds. The Lake is part of the South East Coastal Salt Lakes Nationally Important Wetland Site, and is listed on the Register of the National Estate.

A sudden increase in water depth, combined with increased and prolonged levels of nutrients entering the lake, can cause growth of photosynthetic bacteria in the lake and this occurred in the early 2000's, with blue-green algal concentrations peaking in 2005.

A weir constructed at the entrance to the lake has limited inflows from the sea into the lake and slightly reduced the movement of sand up into the lake. However, despite the presence of the weir, sand has been carried into the lake via the artificially constructed outlet channel, which needs to be dredged annually to keep it open and allow inflows from the sea. If there is sufficient head in the lake through discharge of water from Drain M, the outlet will self-cleanse and there is no need to maintain the outlet through dredging.

Changes in the estuary entrance configuration, such as construction of entrance breakwalls or changes to channel dimensions, have been documented in previous studies (Nielsen and Gordon 2007) to cause changes in the tidal characteristics of estuaries. If there is insufficient tidal flow within the outlet channel and littoral drift is allowed to get into the channel, the channel would silt up and tend toward closure, requiring intervention such as dredging to keep it open. Thus, there is a need to understand the balance between the water levels in the lake and tidal flows so as to best meet the needs of the environment and community. This could be done by such measures as modifying the existing weir configuration, channel dimensions or by constructing entrance training walls at the entrance. Sufficient data and tools are available to allow such an analysis to be undertaken of the Lake George estuary. This analysis of the entrance has been undertaken using the US Army Corps of Engineers Channel Equilibrium Area (CEA) model, which can be used to predict future changes to the tidal regime, changes to tidal currents and hence bank stability within the estuary entrance reaches.

Management options for optimising the lake outlet configuration have been considered within this report, which has been undertaken in conjunction with a coastal processes and management study for Rivoli Bay (WorleyParsons 2015). Therefore, management options would need to consider the coastal processes within the Bay and be consistent with those options as presented for the Rivoli Bay foreshore.

1.1 Role of various agencies

Several SA Government Agencies have responsibility for management of Lake George and the associated drainage network. The management of estuaries within the SE region is mainly the responsibility of the SE Natural Resources Management Board, the South Eastern Water Conservation and Drainage Board (SEWCDB), and the Department of Environment, Water and Natural Resources (DEWNR). The SEWCDB has responsibility over the management of water into and out of Lake George, and is responsible for administering the drainage network within Lake George catchment, including Drain M and the outlet channel to Rivoli Bay.

Primary Industries and Regions SA (PIRSA) is the custodian of South Australia's fisheries. It is responsible for developing and implementing appropriate rules and regulations to control fishing and aquaculture activities in the State. The division manages licensing and registration requirements, permits and exemptions, fishing closures, aquatic reserves, develops environmental and aquatic animal health programs. The South Australian Research and Development Institute (SARDI) which is administered by PIRSA provides research and development services to the state government, commercial clients and research partners and has undertaken research into fish stocks and the overall ecological health of Lake George.

Wattle Range Council has a role in promoting the social, environmental and economic values of the lake. Tourism is a major driver for Beachport and Lake George is a key destination. There are also strong community links to the site for recreation. Council has established the Lake George Management Committee under the Local Government Act. Representatives on the committee include DEWNR, SEWCDB, PIRSA, the South East Amateur Fisherman's Association, South Australian Field and Game Association, Beachport District Development Association, local landholders, Council and community.

Figure 1 - Lake George (Hobbs and de Jong, 2009)

2 ESTUARINE PROCESSES

2.1 Introduction

An understanding of the estuarine processes at Lake George has been developed from the analysis of existing data and site observations complemented with the known understanding of the lake processes as described in previous studies.

2.2 Natural Lake Processes

Lake George and Rivoli Bay formed as a result of a breach in the Robe Range as sea levels rose by up to 140 m following the most recent glacial maximum. Due to the sea level rise and breaching of the Robe Range, a saltwater lagoon was formed in what are now lakes Eliza, St Clair and George. Following stabilisation of sea levels to around the present level about 6,000 years before present, modern beach ridges led to the westward progradation of Rivoli Bay, closing off the southern inlet to Lake George with marine sand (Lake George Management Committee, 2006). Around 1,000 years ago, a north-easterly dune drift isolated Lake George from Lake St Clair. Since that time, climatic, oceanographic and human factors have led to sections of the coastal sandy shoreline to be blown onto the pre-existing Pleistocene calcarenite dunes (Lake George Management Committee, 2006).

The Lake in its natural state was a land-locked body of water, fed by freshwater springs, rainfall and overland runoff. In its natural state, there was no significant natural connection to the sea. However, there is anecdotal and geomorphic evidence that the Lake would overflow toward the south-west from time to time, through the current township of Beachport (de Jong, 2007). The natural salinity of the Lake would sometimes exceed that of the sea, being hypersaline, due to evaporation and concentration of salinity within the Lake during the hot, dry summer months.

There has been research effort involved in understanding the salinity of the Lake as well as the main hydrological inflows and outflows. Australian Water Environments (2009) undertook a study of the water and salt balance within Lake George which included modelling the following inputs and outputs from the system on a daily and monthly timestep:

- Direct rainfall
- Groundwater flux
- Evaporation.

Other inputs and outputs which are a result of modifications made to the Lake environment include:

- Seawater inflow from the outlet weir at Beachport
- Outflow through the outlet weir
- Inflow from Drain M.

2.3 Modifications to the natural system

The natural system of Lake George has been modified extensively due to human activity. In particular, the following modifications have had the greatest influence (Hobbs and de Jong, 2009):

- Construction of an outlet channel connecting Lake George to the sea at Beachport (completed in 1914)
- Sutherland's drain, draining the agricultural land to the south-east of Lake George, constructed in 1915
- Drain M, which commenced construction in 1915, and was completed to its present state in 1966. Connections between Bool Lagoon and Lake George and Callendale regulators were established by 1966.
- Timber logs were used to regulate the outflow through Drain M since the 1980's. Concrete logs were subsequently added to the Lake George outlet in an attempt to prevent sand from moving into the lake (1991).
- Drain M Diversion channel was constructed between Drain M and Middle Lake in 2000
- Works were undertaken to improve the flow path through the flood tide delta at the Lake outlet as well as improve the flow path between Little Lake and Middle Lake in 2006 and 2009. Works have been undertaken to remove sand from the Lake George outlet channel since 2000 and confine the channel to a narrower width.

The extensive agricultural drainage network which supplies water to Lake George via Drain M is illustrated in Figure 2.

Impacts on the Lake due to the above changes to the natural system have been extensive. In particular, the following impacts on the natural system are likely to have occurred:

- Changes to the natural salinity and water balance within the Lake when compared with the natural regime, due to freshwater and nutrient inflows from Drain M and seawater inflows through the Lake connection to the sea;
- Associated changes to the ecology of the Lake, including changes to fish species assemblages, changes to fringing vegetation and benthic algae species as a response to changing salinity ranges and water level fluctuations as well as stocking of the Lake with fish species introduced due to the connection with the sea;
- Growth of a flood tide sand delta within the Little Lake, as a result of sand being transported into the Lake via the outlet channel to Rivoli Bay. It has been estimated that over 500,000 m^3 of sand had been transported into the outlet channel of Lake George until 1980 (Short and Hesp, 1980), forming an extensive flood-tide delta in the Little Lake; comprising sand sourced from Rivoli Bay and the Beachport foreshore.
- Changes to the nutrient balance within the Lake due to the introduction of nutrients via the agricultural drains, allowing phytoplankton blooms to occur; and
- Impacts associated with recreational use of the Lake foreshore, including impacts on fringing vegetation from off-road vehicles.

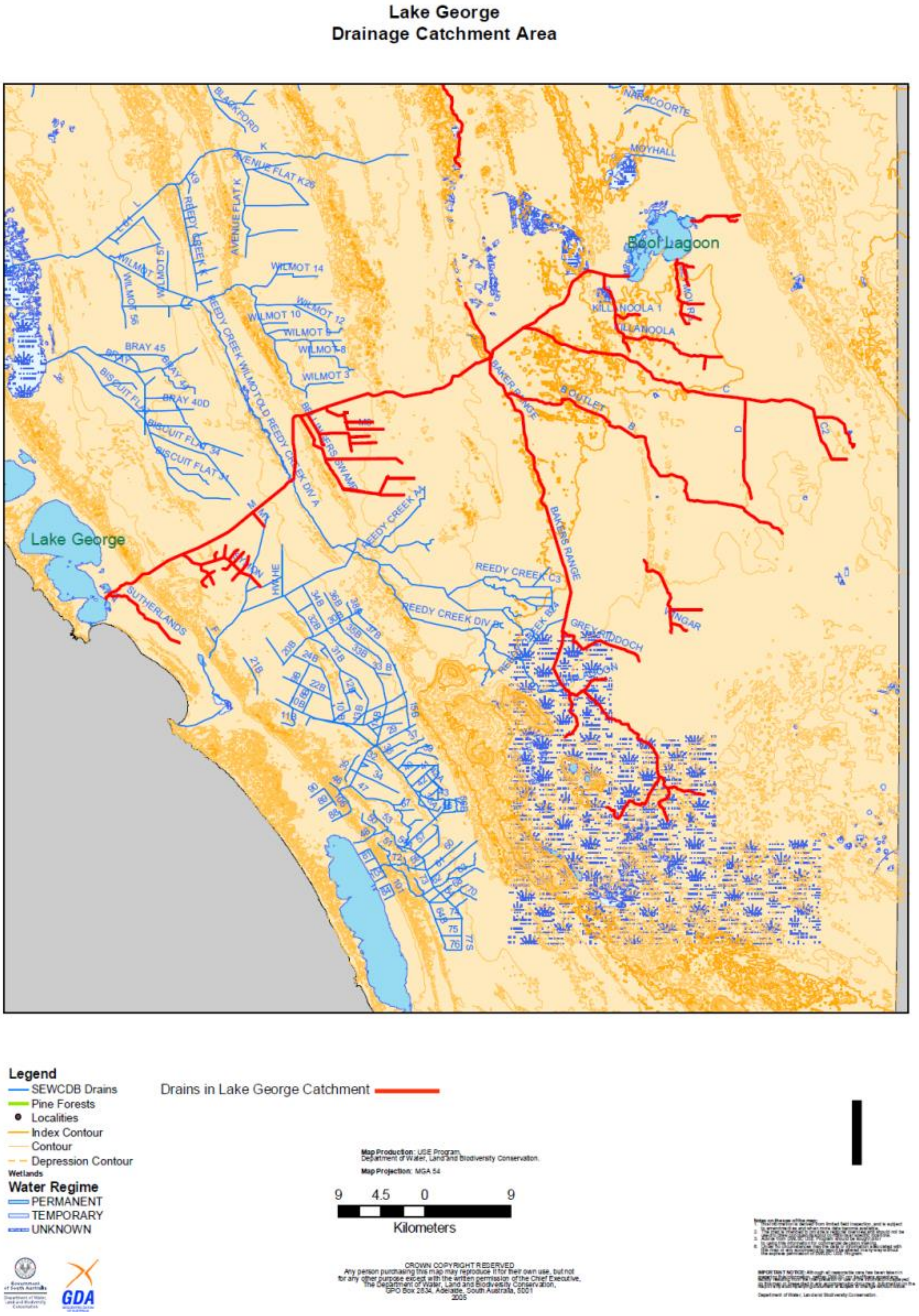


Figure 2 – Lake George Drainage catchment area (Hobbs and de Jong, 2009)

2.4 Water and Salt Balance

Australian Water Environments (2009) undertook a study of the water and salt balance within Lake George. The main freshwater source into Lake George, apart from direct rainfall, is water from the Drain M catchment. The downstream portion of the Drain M catchment contributes a mean annual flow of 22,300 ML and the upstream catchment contributes an average annual flow of 36,000 ML. The inflow from Drain M is seasonal with the predominant inflows occurring from July to October (Australian Water Environments, 2009).

Average monthly discharge from Drain M into Lake George between 1972 – 2006 is provided in Figure 3, and annual discharge is provided in Figure 4. It can be seen that inflows into the Lake from Drain M are highly variable and that average annual discharges since the late 1990's have declined. Factors that have led to the decline in freshwater inflow include agricultural practices, particularly plantation forestry in the drainage catchments (Hobbs and de Jong, 2009). Future changes to climate, including rainfall and evaporation, may also lead to changes in the volume of freshwater inflows.

There is additional inflow through the Woakwine drainage network and Sutherland Drain but there is no information on the volume of water from these sources that discharge into Drain M (Australian Water Environments, 2009).

There has been limited inflow from the sea into the Lake due to sand frequently blocking the outlet channel connecting Little Lake to Rivoli Bay. The outlet had been excavated of sand several times between 2001 and 2008. In particular, the outlet was excavated in May, July and September 2008, with sand building up and choking the outlet within a few weeks on each occasion (Hobbs and de Jong, 2009). The history of the management of the outflow channel is illustrated in Table 1.

Table 1 – Weir management history, Outlet regulator, Lake George (Hobbs and de Jong 2009)

Year	Logs out	Logs in	Comments
1988-1989			excavation in silt area to provide channels to the main outlet from the bed of the lake
1991	march	May-91	construction march 1991, logs used no dates recorded
1992			more concrete logs purchased and used no dates recorded
1993		oct	
1994	no record of outlet		gantry constructed
1995	no record of outlet		groynes extended
1996	august	nov	
1997	march	sept	
1998		oct	
1999	april/may/june		
2000	april	july,sept,oct	Diversion Drain from Drain M to Middle Lake constructed in May 2000
2001	feb, may	sept	Outlet Excavated in May, all logs removed by 19 May
2002	may	1 row nov	2m high x 400m long rock wall reconstructed on Eastern Side of Outlet channel in December 02. Outlet channel excavated and spoil placed behind rockwall. Mouth between beach and regulator excavated.
2003	16-Jul	oct	Mouth between beach and regulator excavated. Logs removed 16 July, some logs added in Oct, fully closed on 5 December
2004	17-Jun	sept	Logs replaced in Oct, centre bay remained open with noted outflow on 29 Oct, water flowing in Dec6. Completely closed 21/3/05.
2005	29-Jul	23-Sep	Mouth between beach and regulator excavated. Sanded over 23 September despite centre bay being open.
2006	9-May	9-Oct	Outlet Channel Excavated, existing 5m wide channel thru delta widened to 35m wide in May.
2007	15-May	18-Oct	Rock wall established on western side of outlet channel, has narrowed channel by a further ~6m. Outlet excavation completed 15 May, 'Sommerville' Channel extended to S by 300m to invert of lake. Flow path to Diversion Drain improved Nth of Drain M.
2008	May, July and September	November	The outlet drain filled with silt requiring three attempts at dredging to maintain an open channel
2009	June	November	One opening was required to maintain an open channel throughout winter and spring

The findings of the salt and water balance for the Lake are illustrated in Figure 5 and Figure 6. It can be seen that inflow from Drain M is generally the largest contributor to inflow in the Lake, although this quantity is highly variable from year to year when compared with rainfall. Inflows from the sea are generally the smallest component. Outflow through the outflow channel is generally the largest outflow flux, as shown in Figure 6, and is strongly correlated with inflow from Drain M.

The modelling found that the volume of inflows from freshwater springs and groundwater into Lake George was small compared with the inflows from Drain M and direct rainfall onto the Lake surface. Total inflows were found to average 105 GL/year over the modelling period, with approximately half of this flowing out to sea. High levels of salinity were measured in Lake George in February 2007 and reproduced by the water/salt balance model, and this could be explained by evapo-concentration processes (Australian Water Environments, 2009).

Three Lake management regimes were investigated in the model:

- Directing Drain M flows away from the Lake when the wet season threshold water levels had been met, and the outlet regulator permanently closed, preventing outflows to the sea;
- Diversion of all Drain M inflows away from Lake George; and
- Reducing the inflow by 30%

It was found that the lake water levels could be maintained at the required thresholds with reduced Drain M inflow if the outlet regulator was closed, preventing outflows to the sea. However, if flows were reduced from Drain M with the outlet regulator kept open, increased inflows from the sea would be required to maintain lake water levels at the historical measured levels.

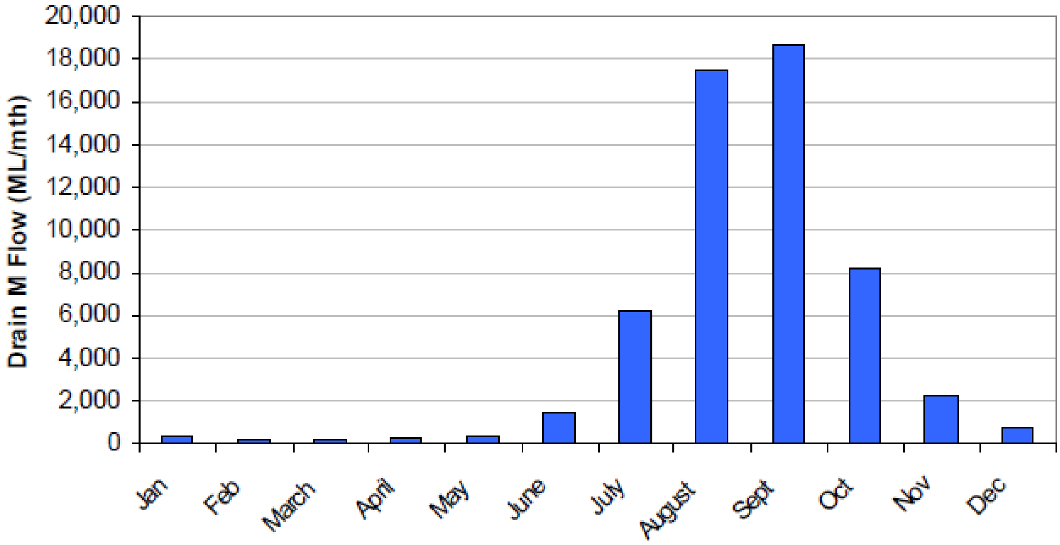


Figure 3 – Average monthly inflow from Drain M to Lake George, 1972 – 2006 (Australian Water Environments, 2009)

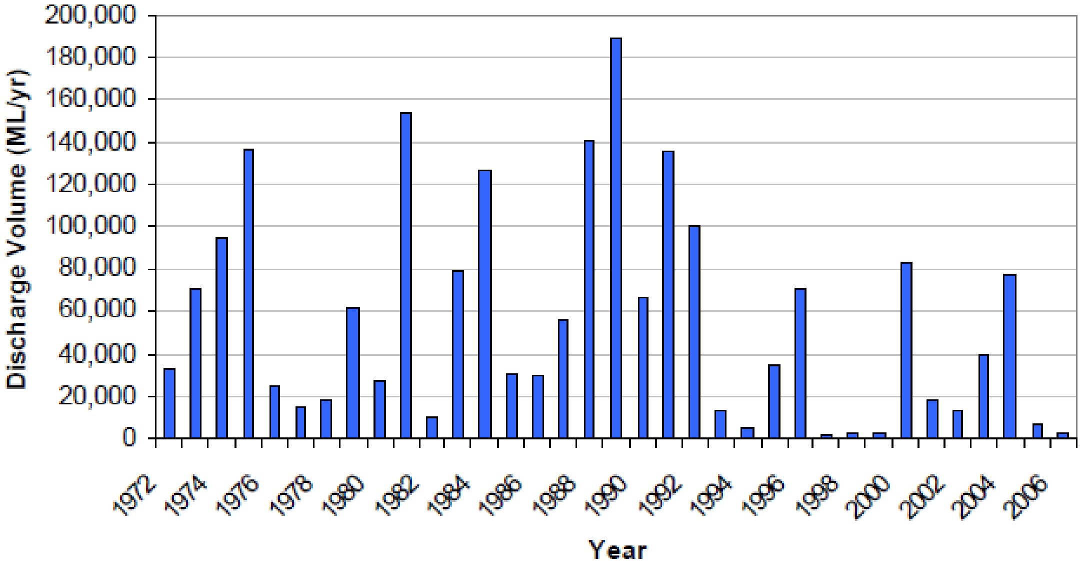


Figure 4 – Average annual inflow from Drain M to Lake George, 1972 – 2006 (Australian Water Environments, 2009)

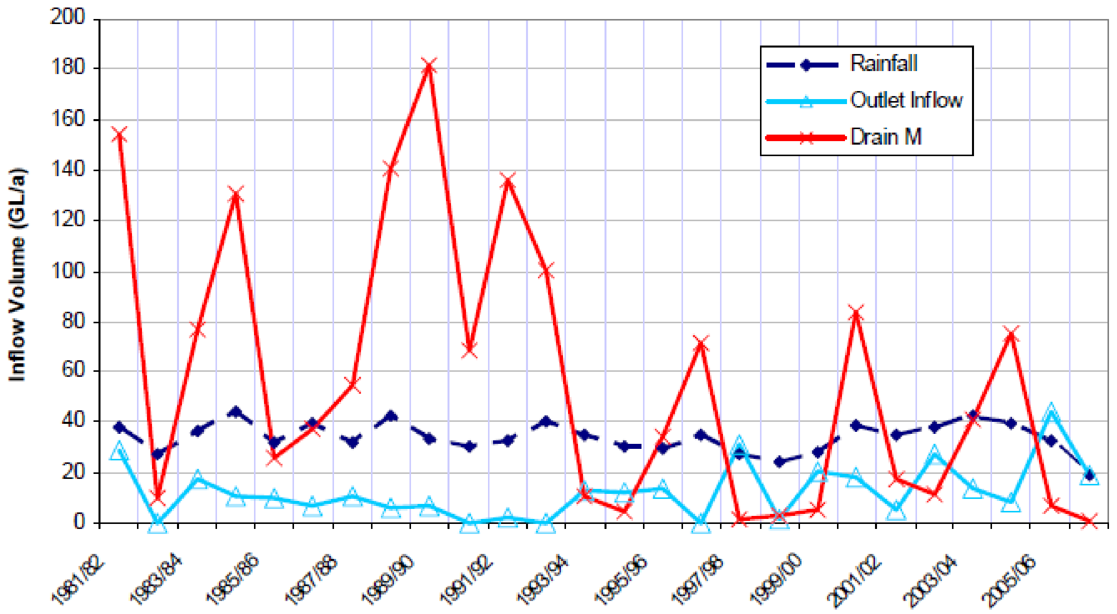


Figure 5 - Inflow contributions to Lake George over time (Australian Water Environments, 2009)

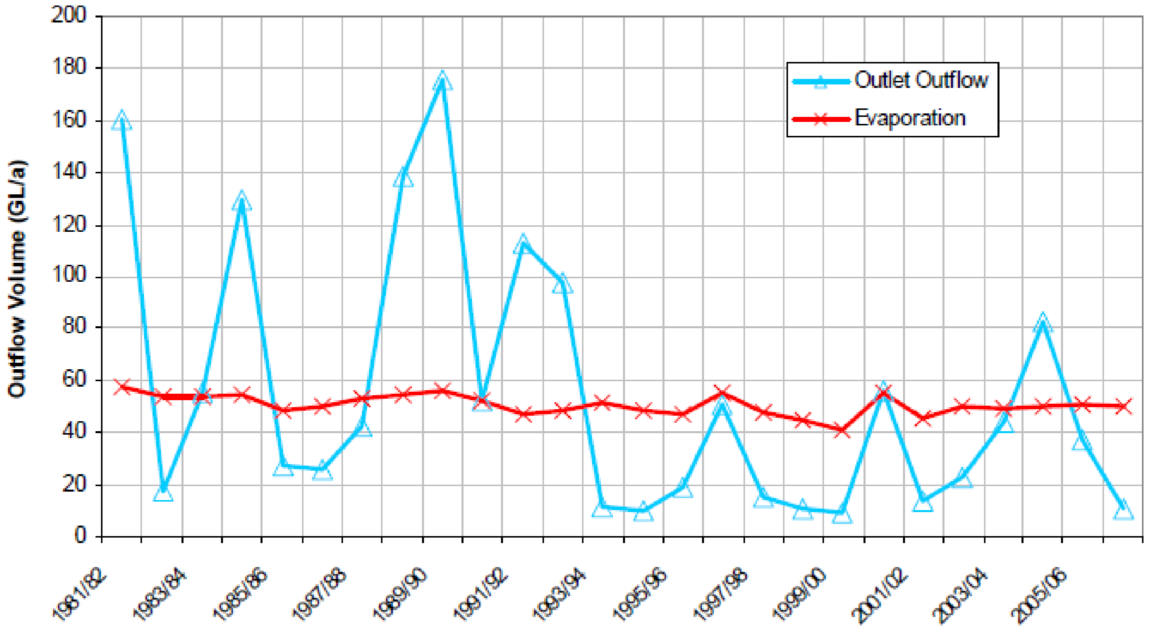


Figure 6 - Losses from Lake George over time (Australian Water Environments, 2009)

2.5 Water Quality

Water quality monitoring of Lake George has been carried out at seven sites within Lake George and three reference sites for comparison purposes in the Lake Robe area, with grab samples being taken on a monthly basis between August 2006 and December 2008 (Hobbs and de Jong, 2009). Water quality parameters measured included:

- Electrical Conductivity (EC)
- Total Dissolved Solids (TDS)
- Turbidity
- pH
- Nutrient analyses, including for nitrogen-based compounds (NH_3, nitrates and nitrites, total nitrogen and total Kjeldhal nitrogen)
- Phosphorus based compounds (including total phosphorus, filterable reactive phosphorus)
- Algal counts, dissolved and total organic carbon, and chlorophyll-a.

Due to dry conditions during the sampling program, water quality sampling was unable to be undertaken at every site on every occasion during the sampling program.

Continuous measurements were also undertaken through the use of a floating buoy system, with two buoys deployed (one in the Big Lake and one in the Middle Lake). Limited data was collected, however, due to low lake levels and vandalism of equipment.

2.5.1 Electrical Conductivity

It was found during the course of the water quality data collection that electrical conductivity values exceeded the expected ranges, indicating a hypersaline environment in the Big and Middle lakes, and a marine hydrological influence in the Lake outlet and Little Lake (Hobbs and de Jong, 2009).

2.5.2 Water Temperature and pH

Water temperature and pH at all sites were measured to be within the expected ranges and did not exceed the ANZECC 2000 water quality guidelines for estuarine and marine waters.

2.5.3 Turbidity

Median turbidity values exceeded the ANZECC 2000 guidelines throughout the monitoring program in the Big, Middle and Little lakes but were lower in Drain M, the lake outlet and at the reference sites in the Robe area (Hobbs and de Jong, 2009).

2.5.4 Nutrients

Levels of ammonia were generally high and on several occasions exceeded levels which are toxic to fish within the Big and Middle lakes and in the outlet channel, which was attributed to stagnant water initiating the growth of nitrifying bacteria. Maximum measured nitrate and nitrite levels exceeded the ANZECC 2000 guidelines but median values were within the guidelines. Total nitrogen levels exceeded the ANZECC 2000 guideline values for most of the samples taken within the Lakes and lake outlet but were especially high in the Middle and Big lakes. Median total phosphorus levels exceeded the ANZECC guideline threshold of 0.1 mg/L in all three lake basins, but were highest in the Big and Middle lakes. Dissolved organic carbon levels exceeded the guideline threshold for all samples in the Big and Middle Lakes.

2.5.5 Chlorophyll-a

Chlorophyll-a levels were recorded to be very high within the Big and Middle Lakes, and were consistently far above the guideline values for marine and estuarine waters of 5 μg/L.

2.5.6 Dissolved Oxygen

Dissolved oxygen was measured using a buoy system continuously deployed between September 2006 and December 2007. The records show that during the summer months, the DO concentrations drop and frequently fall below anoxic levels, particularly in the Big Lake. The introduction of sea flows in May 2007 increased water levels and reduced salinity, and assisted in restoring DO to oxic levels (Hobbs and de Jong, 2009).

2.5.7 Findings

The findings of the water quality monitoring program were as follows:

- Lake George has been overwhelmed by nutrients, particularly organic carbon and nitrogen-based compounds;
- Blue-green algae is the dominant phytoplankton assemblage and currently dominates the biomass of the lake;
- The lakes are considered to be hypereutrophic (due to high concentrations of algae and nutrients), turbid and hypersaline, particularly the Big and Middle lakes. Nutrient concentrations were lower in the Little Lake – this was considered to be because it is seasonally dry and nutrients can oxidise and be lost from the system. In contrast, the Big and Middle Lakes are permanently inundated with no means of flushing and so act as a sink for nutrients. Disturbance of benthic sediments within the Big and Middle Lakes due to their shallow depth allows nutrients to be released into the water column.
- The primary sources of nutrients into the system were yet to be determined with certainty as the analysis of nutrient inflows from the agricultural drains was unable to be carried out due to low water levels.

Brookes and Aldridge (2007) undertook a study on the sediment oxygen demand, nutrient release and water quality of Lake George. Sediment oxygen demand, nutrient release and nutrient content were measured at a number of sites in Lake George. It was found that the lake has transitioned from a clear water, macrophyte-dominated lake to a turbid, phytoplankton-dominated lake. Nutrient levels and sediment oxygen demand were found to be very high, with the both the lake sediments and catchment area playing a role in supplying the lake with nutrients. That report recommended investigating the inflows from Drain M and investigating the degree of stratification that occurs within the Lake.

2.6 Fish

Lake George formerly supported an important inland waters fishery for many years, primarily yellow-eye mullet, which was used by commercial and recreational net fishers (Ye *et al*. 2002). The annual commercial catch of mullet averaged 19 tonnes between 1989 and 1998 with a peak of 51 tonnes in 1995 (Ye, *et al.* 2000). Siltation of the lower lake basin led to a significant reduction in water levels since the early 1990s, with a major fish kill occurring in February 1999. Since April 1999, a moratorium on fishing has been enforced on the lake in an attempt to allow fish stocks to recover from this event.

It was found that fish numbers within the Lake had started to recover following the fish kill, and that mullet that were able to move in from the sea were restricted to the Little Lake, indicating limited connectivity for fish passage between the Little Lake and the Middle and Big lakes. Fish surveys conducted in 2002 showed that there was some recovery of the benthic macrophyte *Chara*, which is an important habitat for fish, and that small fish species (hardyhead and gobies) had recovered with great numbers, providing food for larger fish and water birds. The *Chara* abundance was correlated with water depth, with the *Chara* being more abundant in the shallower areas below 0.5 m depth.

The abundance and diversity of waterbirds in the Lakes is an indicator of the availability of suitable food and habitat. Ye *et al* (2002) noted that all previous fish kills have been associated with low water levels and poor water quality during summer, and that the freshwater inflows from Drain M and the connection to the sea are important for the management of water levels and water quality.

It was assessed that the connection between Lake George and Rivoli Bay was important to allow both young and adult mullet to enter the Lakes (Ye *et al.* 2002). Fish caught during the fish surveys undertaken in 2001 included yellow-eye mullet, black bream, Australian Salmon, greenback flounder and congolli, with black bream and yellow-eye mullet being the most abundant. All the observed fish species are closely associated with estuarine environments. Catch rates of the various fish were below historical levels prior to the major fish-kill of 1999.

Ye *et al* (2002) recommended that closure of the commercial and recreational fishery be retained to protect fish breeding stocks until future fish surveys reveal a recovery of the fish population. It was recommended also that fish passage be improved between the Little Lake and the Middle and Big lakes, and that the social and economic value of fishing in Lake George be assessed. Monitoring of waterbird populations, and the rigorous assessment of the impact of large scale maintenance works on waterbirds was also recommended. Monitoring of water levels and maintaining an ongoing connection between the lake and the sea as well as freshwater inflows from Drain M were considered to be important factors in maintaining ideal conditions for fish.

2.7 Hydrodynamics of the outlet channel

It has been noted in several studies (including Ye *et al* 2002, Hobbs and de Jong, 2009) that the existing ecology of the Lakes is dependent on the connection with the sea, and that this channel has rapidly in-filled with beach sand on many occasions, despite being excavated many times. The Lake water levels are managed by means of a weir at the outlet, with logs at the weir typically removed in the early winter to allow ocean flows into the lake, and replaced again in spring to retain the water within the Lake during the summer months when freshwater inflows into the lake are low. However, the weir has not been effective in retaining water levels in the lake.

The siltation of the channel has led to the requirement for the Drainage Board to dredge the outlet channel periodically to allow the exchange of ocean water with the Lake, as the siltation of the channel does not allow efficient exchange of the water between the Lake and the sea, making it difficult to maintain the lake levels within the required target ranges specified in the Lake George Plan of Management (Lake George Management Committee, 2006).

To understand the propensity for the channel to fill with sand, despite attempts to excavate it and manage the channel velocities by altering the configuration of the outlet weir, a tidal inlet analysis has been undertaken on the outlet channel connecting Lake George to the sea using an Escoffier analysis (Escoffier, 1940). This analysis is described in detail in Appendix 1. When the maximum velocity in the channel is equal to the equilibrium tidal velocity, the cross-sectional flow area is in equilibrium and the entrance is stable. When the maximum velocity is lower than the equilibrium velocity, the current is not strong enough to move the sediments carried into the inlet by littoral drift and the sediments will be deposited into the entrance, reducing the cross-sectional area. When the maximum velocity is higher than the equilibrium velocity, the sediment transport capacity of the inlet currents will be larger than the volume of sediment carried into the inlet entrance by littoral drift and the entrance will therefore erode and the cross-sectional area will increase.

The Escoffier analysis (Appendix 1) found that the channel geometry when compared with the Lake tidal prism is such that the channel will always tend to silt up, despite attempts to keep it open by managing the outlet regulator and excavating the channel.

Further impacting the stability of the Lake outlet is the supply of littoral drift to the outlet from the south. Bruun (1978) presents a method for evaluating the stability of a tidal inlet where the inlet stability is graded in terms of the ratio between the tidal prism (Ω) and the total longshore sediment transport flux (M_{tot}). If the ratio between Ω and M_{tot} is greater than around 150, conditions at the lake ocean inlet are relatively good with a small offshore bar and good tidal flushing. For conditions where this ratio is less than around 50, the ocean inlet conditions are considered to be “poor” – i.e. the outlet is considered to be unstable and tends to close over due to input of littoral drift.

For the Lake George outlet, the ratio of tidal prism to sediment transport flux is estimated to be around 20, indicative of “poor” ocean inlet conditions – i.e. the outlet is considered to be unstable and tends to close over due to input of littoral drift.

3 ASSESSMENT OF EXISTING MANAGEMENT ISSUES

3.1 Introduction

Lake George is faced with several management issues, owing to the present multiple uses of the lake and the modification of the lake environment and ecology due to changes in the workings of the natural system.

Management issues experienced at the Lake and discussed herein include:

- **Pressures on the lake ecology** – caused by accumulation of nutrients in the lake system, and a decline in freshwater inflows and inflows from the sea leading to hypersalinity, fish kills and toxic algal blooms;
- **Water level management** – water level target ranges have been set by the Lake George Management Committee to balance recreational usage and ecological values but these have been unable to be achieved due to reduced freshwater and seawater inflows;
- **Recreational values** – allowing access to the Lake environs for a range of recreational activities compatible with the ecology of the lake;
- **Fishing** – whether it is feasible to re-establish recreational and commercial fishing within the lake and what would need to be done to facilitate this.

The issues are discussed in more detail below.

3.2 Lake Ecology

The Lake George area has an extremely diverse population of birds, with over 200 species being recorded in the vicinity of the Lake (Lake George Management Committee, 2006). Of these, the rufous bristle bird and the olive whistler are noteworthy species for which the nearby Beachport Conservation Park was dedicated (Lake George Management Committee, 2006).

The bird and mammal populations of the Lake rely upon the integrity of their habitats, with future lake levels and seasonal fluctuations playing a significant role in determining the ongoing viability of these communities. High lake levels for extended time periods can cause significant damage to fringing tea-tree vegetation, and regular drying of the lake bed allows oxidation of organic deposits. To maintain the biological diversity of the lake system, seasonal variability in the lake water level is required, with high lake levels limited to short periods in winter and spring, and low lake levels to expose the lower lake flats in autumn.

The vegetation of the lake environs varies according to the underlying geology and soil type, as well as land use impacts. Along the western side of the lake, vegetation varies from typical South Australian coastal foredune scrub, fringing herblands and low open forests around the lake shore. Along the eastern foreshore of the lake, much of the original vegetation has been cleared and sown to pasture, with the predominant vegetation types being sedges and rushes along the lakeshore (Lake George Management Committee, 2006).

The main pressures on the lake ecology have resulted from fluctuations in water levels outside of the target ranges set by the Lake George Management Plan. Specifically, low water levels caused by a reduction in freshwater inflows and closure of the outlet to the sea by accumulated sand has led to a drop in water level, accumulation of nutrients and hypersalinity, which has resulted in blooms of blue-green algae, fish kills and die-back of the *Chara* aquatic macrophytes. This in turn has affected the viability of waterbird populations, with the largest impact occurring when water levels are very low.

Secondary impacts on the ecology include impacts as a result of adjacent recreational uses as well as agricultural uses such as plantation forestry (which can influence the water table and quantity of freshwater flows reaching the Lake) and grazing (which can have an impact on the adjoining fringing vegetation).

3.3 Water level management

The Lake George Management Committee (2006) has set water level thresholds to balance the competing recreational and ecological needs of the Lake.

There is a need to sustain water levels within the Lake that would not damage adjacent pastures and vegetation, as well as maintain sufficiently high summer and autumn water levels to permit a range of water-based recreational activities. Water levels need to be managed to meet the following criteria:

- Water levels need to be kept low enough to prevent degradation of the adjacent low-lying pasture lands;
- Water levels need to be kept high enough to allow recreational use of the lakes for water skiing, sailboarding and fishing;
- Water levels need to be low enough to allow fringing vegetation of the lake to be protected from inundation for part of the year and from erosion due to waves, but high enough to preserve the aquatic vertebrate and invertebrate fauna.

With these broad objectives in mind, the Lake George Management Committee has set the following targets for lake water levels:

- A winter/spring peak water level of 0.58 m AHD and minimum of 0.42 m AHD;
- A summer minimum water level of 0.13 m AHD which allows mudflats to be exposed, leading to a healthier habitat for migratory waders.

These water levels have not been able to be maintained over the historical record, as indicated in Figure 7, below. In particular, lake water levels have been consistently below the minimum summer threshold since mid 2005. Levels were also below the minimum summer threshold between 1997 and 2000, culminating in a major fish kill which occurred in early 1999. High lake salinity values (much higher than the values found in seawater) coincided with low water levels as can be seen in Figure 7.

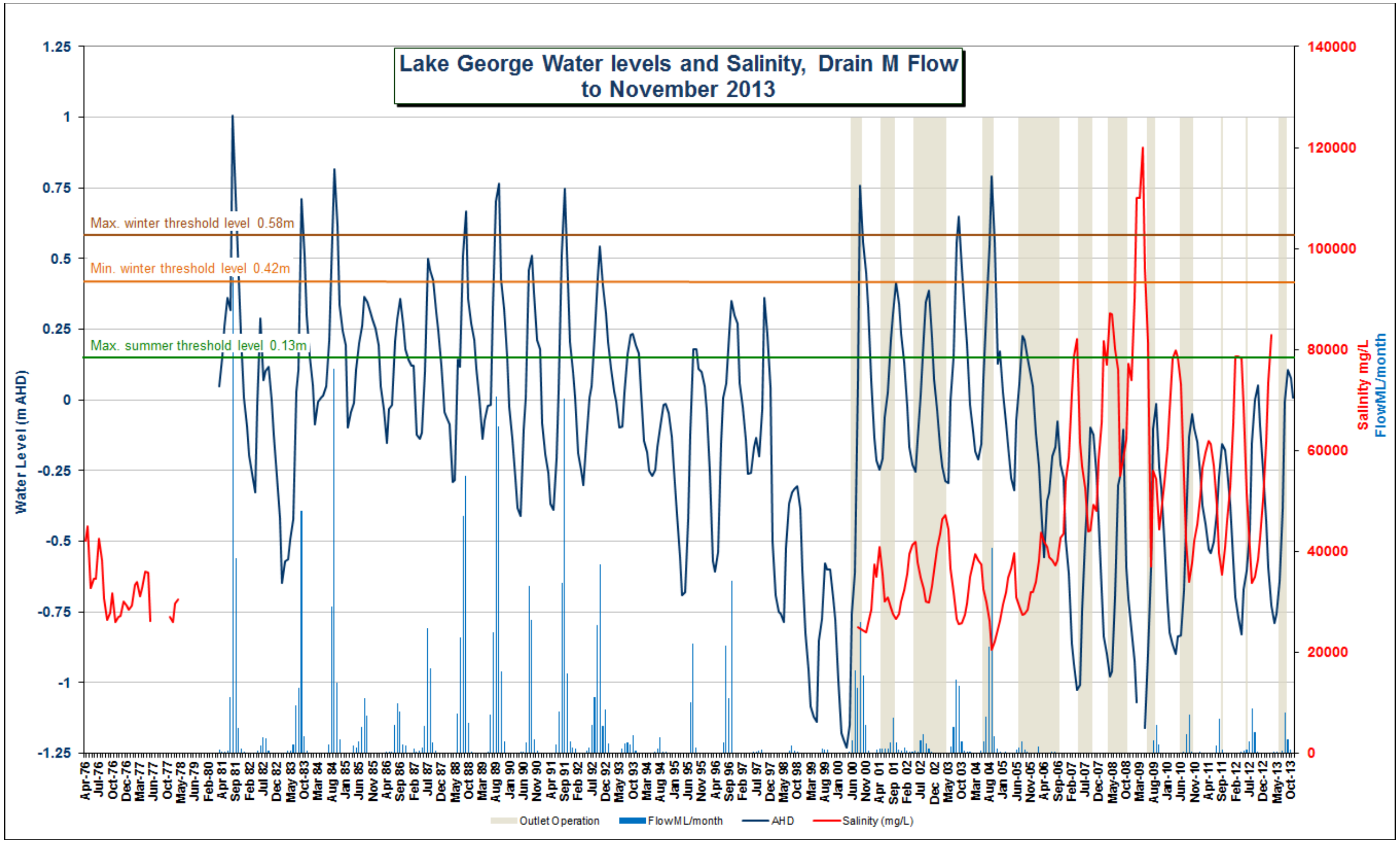


Figure 7 – Recorded Lake George water levels, thresholds, salinity, outlet operation and Drain M inflows

3.4 Recreational Values

Lake George supports a variety of recreational uses, including the following:

- Passive recreation, including sight-seeing, picnics and swimming
- Sailboarding, boat launching/retrieving, camping, fishing, four-wheel driving and duck-hunting.

These activities depend on public access to the foreshore being maintained or improved. Public access to many parts of the lake foreshore is impeded by several factors including fluctuating water levels, the rough state of some of the roads and tracks around the lakes, private ownership of the land and a lack of public access points for day visitors, camping and recreation. Improved access to the foreshore is one of the objectives of the Lake George Management Plan, recognising that the areas of the lake which have conflicting uses should be managed in such a way that the long term viability of the resource is not threatened by unsustainable or unjustified public access (Lake George Management Committee, 2006).

Camping is a popular pastime at the Lake, with length of stays varying from one night up to a month. Management issues relating to camping include the number of people, length of stay, location of camp sites, destruction of vegetation for use in campfires and litter pollution.

Water-based recreation is a popular activity also, with the Lake being used for the launch of water craft, sailing, power boating, water skiing and fishing. Water levels in the lake need to involve a compromise between the varying recreational uses of the lake, with water levels being high enough to enable these uses to take place but low enough to still allow vehicular access to the lake edge (Lake George Management Committee, 2006).

Impact of recreational use on the lake foreshore includes the impact of vehicles on fringing vegetation (as can be seen in Figure 8), pollution and litter. Off-road vehicles can have a big impact on the surrounding vegetation if unmarked access tracks are used.

Figure 8 – Destruction of fringing vegetation at Lake George due to traffic from off-road vehicles. Note contrast between fenced-off area where vehicles cannot access and the trafficked area in the foreground.

3.5 Fishing

A major issue for Lake George is the collapse of the former fishery within the Lake, which has had a significant impact on the recreational values, tourism and local economy.

Lake George has low fish species diversity, due largely to widely fluctuating salinity levels, and large variations in water levels, temperature and oxygen supply.

Prior to the major fish kill and subsequent moratorium on fishing in 1999, Lake George sustained a commercial fishery and recreational fishing was a popular activity in the Lake. In particular, yellow-eye mullet and Australian Salmon were two of the most common fish species caught by commercial and recreational fishermen. Associated with the fish kill in 1999 was the die-back of the benthic macrophyte *Chara*, which was affected by poor light penetration into the Lake waters resulting from a heavy phytoplankton bloom.

Despite signs of recovery of fish stocks since the 1999 fish kill, low lake water levels and high nutrient levels have persisted, thereby limiting the recovery of the fishery. It is a stated objective of the Lake George Management Plan (Lake George Management Committee, 2006) that recreational and commercial net fishing be allowed to continue at a sustainable level, given the importance of the lake and recreational fishing to the economy of the region.

4 STAKEHOLDER AND COMMUNITY CONSULTATION

Stakeholder and community consultation was carried out in Beachport in October 2014 and again during March 2015, with the draft report presented and placed on public exhibition.

The stakeholder consultation included:

- One-on-one meetings with key stakeholders including the Lake George Management Committee and Council at Beachport in October 2014;
- Public drop-in information centre attended by Council and WorleyParsons at Beachport in March 2015
- Stakeholder meetings with Council, DPTI, DEWNR SE and SEWCDB in March 2015;
- Public presentations on the Lake George and related Rivoli Bay studies in Beachport in March 2015;
- Hard copies of the report available at the Beachport Visitors Information Centre and on Council website during duration of the exhibition period which covered March 2015;
- Project information posters on display at Beachport Visitors Information Centre during the exhibition period.

A summary of comments received during the exhibition period included:

- A submission about the historical configuration of the Lake outlet groynes and how sand bypassing at the outlet was more effective in the past. The submission also suggested using seawater to replenish the lake through the use of a pipeline connecting the lake and the sea;
- Discussion during the presentations about the longer term aspirations for the lake, with the need to investigate the ability of the outlet weir to retain water discussed. Anectdotal evidence has suggested that the weir has not been effective in retaining the water, possibly due to groundwater flows beneath the weir. The weir could be re-designed based on known geotechnical conditions at the site at a later date;
- General support for the idea of using the weir to control the ingress of sand into the outlet channel and maintaining the connection to the sea as described in this report;
- Discussion relating to the need to bypass the outlet to prevent erosion of the downdrift beach if the groynes at the outlet were extended;
- Support for enhancing the freshwater inflow to the Lake as a longer term strategy through enhancing flows to Drain M, Sutherlands Drain, providing a freshwater drain connection between Lake Frome and Lake George and by the possible cutting of a freshwater drain connecting the drainage network to the Northern Lake.

5 PRELIMINARY LAKE MANAGEMENT SCHEME

5.1 Lake Management Objective

Management options have been developed and are examined herein, relating primarily to the overall objective of improving the ecology and water quality of the Lake George system as well as the Lake recreational values and the economic value of the Lake as a fishery.

The overall aim of the Lake George Management Plan is *"to maintain and enhance the environmental quality of Lake George and environs through effective management of the areas uses and its continuing evolution for recreation and development".* To achieve this aim and meet the objectives as stated in the Plan, a suite of ongoing management actions are recommended in the Plan.

In addition to the actions recommended in the Plan, improvement of the ecology and water quality of the Lake George system, recreational values and the economic value of the Lake as a fishery may be achieved through managing the lake water levels within the target range set by the Lake George Management Committee (2006). There has been considerable effort made in recent years to understand the ecology of the lake, through water quality monitoring, assessment of fish stocks, sediment analysis and monitoring of waterbird populations. There has also been some effort to improve the connectivity between the Little Lake and the Big and Middle Lakes, in particular by excavation of a drainage channel connecting the two sections of the Lake. The previous studies have made a number of recommendations in relation to water quality monitoring, assessment of fish stocks and a need to understand the nutrient budget of the Lake, particularly the potential for nutrient inflows from Drain M. It is recommended that these efforts are continued.

It is considered that the water quality and ecology of the Lake can be improved through the following means:

- Improved connectivity of the Lake with Rivoli Bay
- Maintaining the water levels within the target ranges set by the Lake George Management Committee (which are considered appropriate based on review of the available information and consultation with the Committee)
- Enhancing the supply of fresh water to the Lake system via Drain M and the interconnected drainage network, including transfer of freshwater from the Lake Frome to Lake George catchment.

This would bring also a flow-on effect of enhancing the Lake's recreational values. It is recognised that enhancing the supply of freshwater to the lake system is dependent on climatic factors, landuse within the catchment area and the need to manage water supplies to other systems within the South East region. There is limited scope to control these factors at present, although as recognised in existing studies, concerted effort needs to be made to manage the activities within the Lake catchment to improve the water supply and reduce the nutrient load reaching the Lake. The South Eastern Water Conservation and Drainage Board (SEWDCB) are responsible for monitoring net drainage inflows to the lake and subsequently managing the outflows through the outlet regulator but have limited control over the amount of fresh water that can reach the system via the drainage catchments.

It is considered that there is more control possible over the connection between the Lake and the sea to achieve the overall management objectives for the Lake. The management scheme described below has, therefore, considered what can be done to enhance the Lake connectivity with the sea in light of the existing studies and data, as well as achieving an outcome which is consistent with the recommendations for managing the Beachport foreshore (WorleyParsons 2015).

5.2 Lake Management Options

The lake outlet management options considered below include:

- Modifying the channel configuration to allow the channel to remain open naturally due to scour by tidal flows;
- Closing the outlet channel to restore the “natural” ecology of the system;
- Management of the outlet weir and groynes to minimise the ingress of sand and allow tidal flows to maintain the water levels in the Lakes to within the target levels specified in the Lake George Management Plan (Lake George Management Committee, 2006).

These options were presented to the community and key stakeholders in March 2015.

These options are discussed below.

5.2.1 Modifying configuration of outlet channel

Continuing sand entrainment into the Lake George outlet channel over time has led to the siltation of the lower basin area and outlet channel of Lake George and the growth of a flood tide delta over time, with up to 500,000 m^3 of sand having built up between the 1950’s and the early 1980’s, as evidenced by examination of historical aerial photography. Through sand sampling conducted for the study of Rivoli Bay (WorleyParsons 2015) it is evident that sand has been continuing to be deposited into the outlet channel at Lake George and that the source of this sand is from the beach to the south of the outlet.

The Lake water levels are managed by means of a weir at the outlet, with logs at the weir removed typically in the early winter to allow ocean flows into the lake, and replaced again in spring to retain the water within the Lake during the summer months when freshwater inflows into the lake are low. However, the weir has not been effective in retaining the water levels in the lake.

The siltation of the channel has led to the requirement for the Drainage Board to dredge the outlet channel periodically to allow the exchange of ocean water with the Lake, as the siltation of the channel does not allow efficient exchange of the water between the Lake and the sea, making it difficult to maintain the lake levels within the required target ranges specified in the Lake George Plan of Management.

Therefore, the configuration of the outlet channel was examined to determine whether there is any scope to modify the channel dimensions to improve the tidal flushing of the lake, improve the hydraulic efficiency of the channel and, therefore, reduce the requirement for maintenance dredging of the outlet channel and ongoing siltation of the Lake. This was done by means of an Escoffier analysis of the outlet channel, which is detailed in Appendix 1. It was found that it would not be feasible to modify the outlet channel such that the cross-sectional area is in a stable equilibrium, as the channel would need to be excavated to a much greater width and depth than exists at present and severe bank erosion could result. In addition, increasing the channel dimensions to a level required to achieve a stable equilibrium would lead to increasing tidal ranges within the lake and a change in the ecology of the lake (including the viability of fringing vegetation) due to the increased tidal range and modified salinities.

5.2.2 Closing the outlet channel (i.e. "do nothing")

Prior to intervention in the natural system, Lake George was formerly closed to the ocean and would have naturally been a hypersaline lake, similar to neighbouring Lake Eliza and St Clair. The Lake would have been fed by rainfall, and groundwater flows from the surrounding catchment area. Should the "do-nothing" scenario be implemented, the connection between the Lake and the sea will be closed permanently and the ecology of the lake will depend on freshwater inflow (which has been greatly reduced from its natural levels and has a higher nutrient load than under natural conditions).

The hydrology of the catchment of the Lake has been altered, with drainage being directed to a network of drainage channels. Australian Water Environments (2009) undertook a study of the water and salt balance under the scenario of all seawater inflows being excluded from the Lake as well as inflows from Drain M. Under this scenario, Australian Water Environments (2009) indicated that the Lake would dry up within four to five years, due to the groundwater flux into the Lake being very small compared with inflow from Drain M.

Due to the fluctuating inflow volumes from Drain M, the possibility that flow volumes from Drain M could be reduced in the future due to diversion of water upstream of Callendale for the Restoring Environmental Flows to the upper South East (REFLOWS) project, and the reduction of flow volume due to landuse in the catchment and potential impacts of climate change, Drain M cannot be relied upon to provide sufficient water to maintain the lake levels within their target range without additional inflows allowed from the sea.

Therefore, it is considered that to maintain the water levels within their target range as well as maintain the estuarine ecology of the Lake and to meet community expectations for the Lake, the connection to the sea will need to be maintained. For this reason, doing nothing and allowing the outlet channel to close would not be a viable option.

5.2.3 Management of the outlet weir and channel

In conjunction with the modification of the Lake outlet channel, the option of extending the outlet groynes beyond the surf zone to reduce the supply of sediment to the Lake was examined. This would provide the dual purpose of creating a build-up of sand immediately up-drift of the Lake outlet, which can be used periodically as a source of sand to nourish the other beach compartments within the Beachport area as required. It is noted that while Rivoli Bay has been accreting over the geological timescale, the opening of the channel to the Lake has resulted in localised beach erosion at Beachport due to sand ingress into the Lake.

A similar option has been put forward in past studies, such as suggested by Tonkin & Associates (1997), associated with the potential construction of a boat ramp at this location.

This option, combined with management of the sand buildup in the outlet channel and management of the concrete logs at the outlet regulator is recommended for the following reasons:

- Sand buildup within the outlet channel can be reduced by extension of the groynes beyond the surf zone at Beachport. This would be due to reduced longshore sediment transport into the seaward end of the outlet channel, thereby reducing the long term frequency of maintenance dredging required and allowing continued exchange of water between Rivoli Bay and Lake George;
- The water level can be maintained within the target range once sand ingress is reduced and the outlet channel is cleared of sand. This could be achieved through maintaining the logs within the outlet regulator throughout the year at a level high enough to prevent ingress of sand into the outlet channel but low enough to allow seawater inflow into the lower lake on the high tide.

While this option presents a viable short-term action to improve the ecology of the Lake, in the longer term the freshwater inflow to the Lake should continue to be enhanced with the view to restoring the natural ecology of the lake and decreasing the lake's dependence on maintaining a connection to the sea, which may not be able to be easily maintained into the future. It should be noted that SEWCDB will not be able to dedicate resources to dredging of the channel in the future. However, dredging will need to be carried out on a single occasion to implement the recommended scheme, with the requirement for future dredging greatly reduced when compared with what has needed to be done in recent years.

The specifics of the recommended management scheme for the Lake outlet are outlined below.

5.3 Recommended Management Scheme

The recommended management scheme for the outlet of Lake George is as follows:

1. Dredge the outlet channel to -1 m AHD on the lake side of the outlet regulator.
2. Dredge the outlet channel to -0.5 m AHD on the sea side of the outlet regulator
3. Maintain the logs within the outlet regulator all year round. Maintain the top of the logs at 0.4 m AHD along the full width of the regulator during the winter months. Remove one row of logs to maintain the top of the logs at 0.1 m AHD through the summer months along the entire width of the regulator structure.

4. Maintain the area on the seaward side of the regulator structure at -0.5 m AHD by maintenance dredging as required. This would then reduce the requirement to undertake maintenance dredging in the channel upstream of the regulator structure.

The scheme is discussed in more detail below.

5.3.1 Dredging of the outlet channel and setting outlet weir level

It is recommended in the short term that:

- The outlet channel upstream of the outlet regulator structure be dredged to -1 m AHD. This will be required to maintain sufficient flows through the channel and to minimise the potential for future maintenance dredging to be required;
- On the downstream side of the regulator, the channel should be dredged to -0.5 m AHD and maintained to a maximum level of 0 m AHD. This would prevent sand from infilling the channel upstream of the regulator, thus limiting the area requiring regular maintenance dredging to the area downstream of the regulator. Ready access for excavator equipment to undertake this dredging is available in the area downstream of the regulator.

It is recommended that the logs at the outlet regulator be maintained at a level around 0.1 m AHD during summer and 0.4 m AHD in winter. The rationale behind this management regime is as follows:

- Tidal exchange between the sea and the lower Lake would be maintained throughout summer and winter, with tidal flows able to penetrate into the channel during high tide and fish passage from the sea able to be maintained;
- Maintaining the logs at 0.1 m in summer would enable the tailwater level in the channel to be maintained at a level consistent with the lower summer target range of the Lake George Management Plan while preventing sand from entering the lake channel;
- Maintaining the logs at 0.4 m in winter would enable tidal flows to penetrate into the lake at high tide while preventing water levels from falling below the lower winter target range of the Lake George Management Plan and preventing excessive buildup of water above the upper target range.

The aim of the above scheme is to maintain the lake water levels within the ranges identified in the Lake George Management Plan. The required levels for the logs to satisfy the water level requirements could be optimised through the use of a numerical hydrodynamic model of the lake and channel, with several scenarios tested including varying freshwater inflows from Drain M and varying the log levels at the outlet regulator. Alternatively, the log levels could be optimised through trial and error of the proposed configuration as presented herein. A section view of the proposed scheme is provided in Figure 9.

From the review of existing studies, the advantages of this scheme would be as follows:

- Salinity within the lakes would not be substantially increased, as the seawater is less saline (35,000 mg/L) than the hypersaline lake water (which averages around 35,000 mg/L but can be as high as 80,000 mg/L, refer Figure 7). The impact of allowing greater seawater inflow into the lakes was examined in Australian Water Environments (2009) and it was found that salinity would decrease when compared with what the salinity would be if water levels were allowed to decrease due to evapo-concentration.

- Fish passage from the sea to the lake would be maintained and improved over the existing conditions which could over time lead to full recovery of the lake fishery.
- Water quality (clarity, oxygen levels and nutrient levels) would likely improve overall as the seawater is generally of higher water quality than the nutrient laden drainage water from the agricultural catchment areas.
- Water levels would be able to be maintained within the target ranges for improved estuary health and recreational amenity, without as much reliance on the unreliable freshwater inflows from Drain M.
- The scheme provides an opportunity for sand to accumulate on the beach at Beachport, which would provide a source of sand to address erosion issues along the Beachport foreshore.
- The scheme can be implemented using existing resources and without modifying the existing outlet structure and has in-principle support of the Lake George Management Committee.

It is recommended that once the above scheme is implemented, it is monitored for its effectiveness and that the monitoring recommended in existing studies be continued. In particular, the following aspects would need to be monitored closely:

- The effectiveness of the outflow regulator in retaining water should be monitored;
- Efforts to increase freshwater inflow to the Lakes and improve the water quality of this inflow should continue to be maintained;
- The condition of the fishery, fringing vegetation, water levels and lake ecology should be monitored following implementation of the scheme with a view to re-opening the fishery should conditions permit and assessing the success of the scheme.

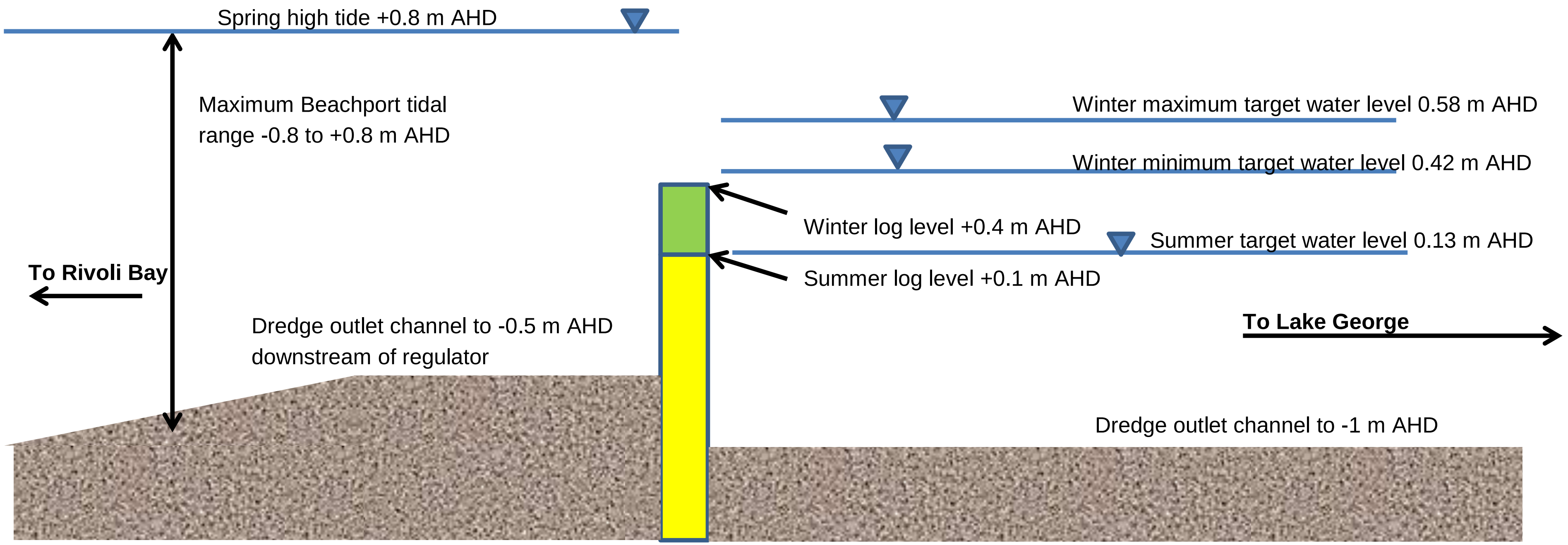


Figure 9 – Section view of proposed lake outlet management scheme (not to scale)

5.3.2 Recommended Long Term Management Scheme

In the longer term, it is recommended that the groynes at the outlet to Lake George be extended beyond the surf zone (i.e. to -2 m contour or deeper) - this would reduce the littoral drift transport into the Lake outlet and, therefore, reduce the required frequency of dredging of the channel and slow down the growth of the flood tide delta. It would also allow greater ingress of seawater into the Lake thus improving the ability of the Lake to meet its water level target range. Extending the groynes is a long term capital investment, which would require significant external funding to be provided. As this is the most expensive component of the proposed scheme it could be considered at a later date, following a trial of the short term scheme described above. Lengthening of the groynes at the outlet would assist in maintaining the connection between the Lake and the sea by reducing the supply of sand reaching the outlet channel. However, in the longer term, limited resources of SEWCDB would limit their capacity to commit to ongoing maintenance dredging work in the outlet channel. While a viable connection to the sea may be able to be maintained for some time through implementation of the short-term scheme described above, it will be increasingly difficult in the future to maintain this connection.

As the connection to the sea will not be able to be relied upon in the future, it will become increasingly important to establish a reliable freshwater inflow to the Lake and to control nutrient inflows and water quality. Efforts to restore freshwater inflow to the Lake from Drain M and the interconnected drainage network should therefore be continued, including establishment of a freshwater flow path from Lake Frome to Lake George. It is understood that the construction of a new drain connecting Lake Frome and Lake George has been investigated by SEWCDB but the ability to deliver fresh water between the two catchments is limited by the flat topography between the two basins.

5.3.3 Extension of the outlet groynes

Extension of the outlet groynes is compatible with the recommended strategy for management of the foreshore of Rivoli Bay at Beachport. However, extending the groynes is a long term capital investment, which would require significant external funding to be provided.

For the Lake George outlet, the ratio of tidal prism to sediment transport flux is estimated to be around 20, indicative of “poor” ocean inlet conditions – i.e. the outlet is considered to be unstable and tends to close over due to input of littoral drift. This ratio may be increased by reducing the supply of littoral drift transport (M) to the lake outlet, thus improving the stability of the outlet. To do this, an effective method would be to increase the length of the groynes at the lake outlet such that the sediment transport bypassing the groynes is lower than is currently the case. This would provide the benefit of reducing the sand supply to the lake. An additional benefit is that a source of sand becomes available that can be used from time to time to nourish the other beach compartments along the Beachport foreshore where erosion may be experienced as a result of storms. Given the low freshwater inputs into the lake, the lake entrance could be dredged as required, with the required frequency of dredging reduced due to the reduced sediment supply as a result of lengthening the groynes at the lake outlet.

While sand bypassing of the groynes is still likely to occur, the volume of sand bypassing the outlet would be reduced by this scheme, provided sand is managed at the updrift side of the groyne and used to renourish the beach compartments on the updrift side at Beachport as recommended in in the Rivoli Bay Study (WorleyParsons 2014). Sand would need to be periodically bypassed to the downdrift side of the groynes to prevent erosion of the beach on the downdrift side.

The scheme is shown in plan view in Figure 10, below. A conceptual design for the upgrade of the groynes is illustrated in Figure 11, below. It is suggested that the additional groyne extend to approximately the -2 m AHD bathymetric contour (although this would likely not preclude all sand bypassing) and be designed such that it would withstand the wave climate experienced at that location. The indicative mass of the rock has been calculated using the Hudson formulation for the locally available rock as discussed in the coastal embayment study for Rivoli Bay (WorleyParsons 2015). The calculation of rock sizes and derivation of the concept design is provided in Appendix 2.

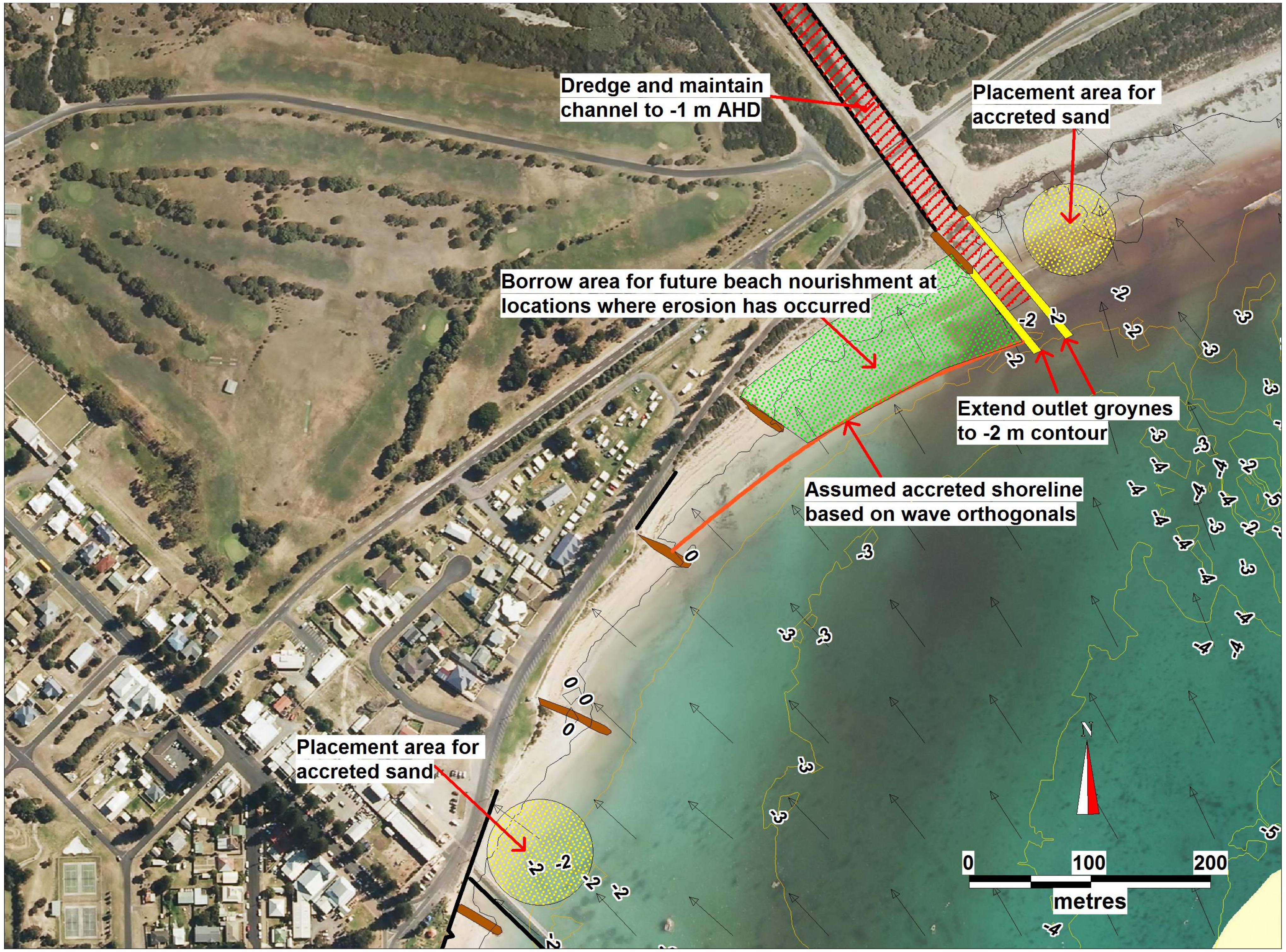
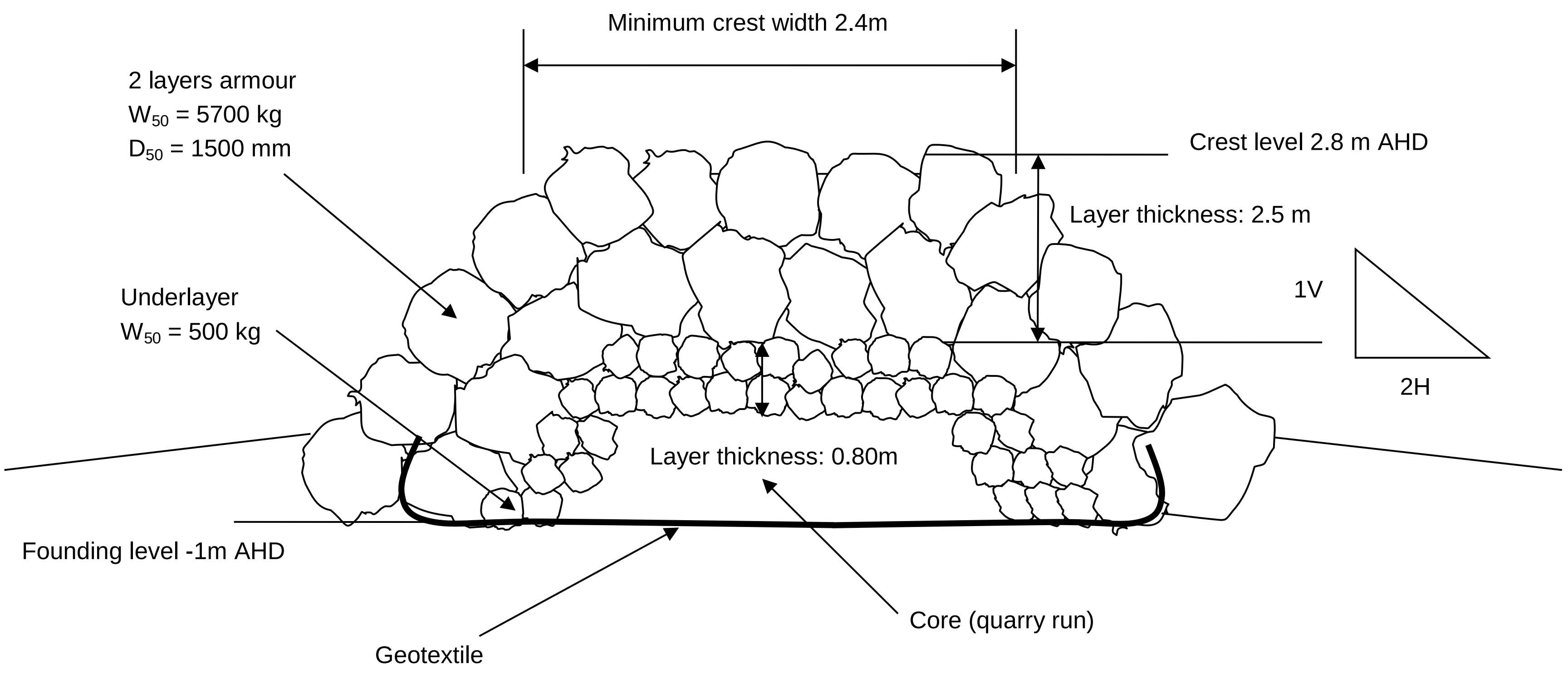


Figure 10 – Potential management scheme for Lake George outlet area



SECTION VIEW

NOT TO SCALE

Figure 11 - Conceptual design for groyne extension at Lake George outlet

5.3.4 Costing

Indicative cost estimates have been prepared for each of the aspects of the proposed management scheme described above.

In the preparation of these cost estimates, consideration has been given to our experience gained from the completion of a number of similar coastal/maritime projects. In particular, we have drawn upon in-house costing information from relevant projects and supplemented this as-required through enquiries with representatives from local quarries and contractors that specialise in this type of work.

The indicative cost estimates for the proposed management scheme are summarised in Table 2. The cost estimates incorporate 30% contingency and an allowance for detailed design where warranted. The cost estimate excludes GST, project management fees, authority approval fees and allowances for Contractor's risk. The cost estimate does not include allowance for design growth, escalation, procurement and construction management.

It should be noted that the cost estimates are indicative only and are likely to change based on the detailed design and variations in market forces.

From the cost estimate, the extension of the groynes is the largest cost item. Should the groynes not be extended as part of the management scheme, it is expected that maintenance costs of periodic dredging of sand from the outlet channel would be higher as this would be required on a more regular basis.

Table 2 - Concept Design - Cost Estimate – Lake George entrance management scheme

Item	Description	Unit	Quantity	Rate	Cost	Source of Rate	Comments
1	**Preliminaries**						
1.1	Site establishment	Item		Lump Sum	$ 15,000.00	WP internal	
1.2	Deployment and maintenance of environmental	Item		Lump Sum	$ 5,000.00	WP internal	
	control provisions						
1.3	Construction survey	Item		Lump Sum	$ 5,000.00	WP internal	
2	**Excavation of existing channel**						
2.1	Excavation of sand from outlet channel to -1 m AHD	m^3	25,000	$ 4.00	$ 100,000.00	Hobbs and de Jong 2009	Rate is based on $37,132 to remove 10,230 m^3 actual cost from Hobbs and de Jong 2009, p 93.
3	**Extend two rock groynes by 100 m**						
3.1	Rock (large, supply & place)	m^3	3,014	$ 120.00	$ 361,728.00	Based on quoted rate of $70/tonne ($120/m3)	
3.2	Crushed filter rock	m^3	880	$ 30.20	$ 26,576.00	Rawlinsons 2012 p677	
3.3	Labour (5 workers for 16 weeks)	hour	3,200	$ 75.00	$ 240,000.00		
3.4	Approvals, Detailed Design				$ 50,000.00		
4	**Site Disestablishment**						
4.1	Site Disestablishment	Item		Lump Sum	$ 10,000.00	WP internal	
			Sub-total		**$ 813,304**		
			Contingency	**30%**	**$ 243,991**		
			Total		**$ 1,057,295**		

Disclaimer

This cost estimate is based on WorleyParsons' experience and judgement as a firm of practising professional engineers familiar with the construction industry.

This cost estimate can NOT be guaranteed as we have no control over Contractor's prices, market forces and competitive bids from tenderers.

This cost estimate excludes GST, design fees, project management fees, and authority approval fees.

6 CONCLUSIONS AND RECOMMENDATIONS

This report has presented a management scheme for Lake George that would assist in meeting the stated objectives of the Lake George Management Plan.

Previous studies relating to the salt and water balance in the Lake, water quality and the condition of the fishery within the Lake have been reviewed and summarised herein.

Lake George is faced with several management issues, owing to the present multiple uses of the lake and the modification of the lake environment and ecology due to changes in the workings of the natural system.

Management issues experienced at the Lake include:

- **Pressures on the lake ecology** – caused by accumulation of nutrients in the lake system, and a decline in freshwater inflows and inflows from the sea leading to hypersalinity, fish kills and toxic algal blooms;
- **Water level management** – water level target ranges have been set by the Lake George Management Committee to balance recreational usage and ecological values but these have been unable to be achieved due to reduced freshwater and seawater inflows;
- **Recreational values** – allowing access to the Lake environs for a range of recreational activities compatible with the ecology of the lake;
- **Fishing** – whether it is feasible to re-establish recreational and commercial fishing within the lake and what would need to be done to facilitate this.

There has been considerable effort made in recent years to understand the ecology of the lake, through water quality monitoring, assessment of fish stocks, sediment analysis and monitoring of waterbird populations. There has also been some effort to improve the connectivity between the Little Lake and the Big and Middle Lakes, in particular by excavation of a drainage channel connecting the two sections of the Lake. The previous studies have made a number of recommendations in relation to water quality monitoring, assessment of fish stocks and a need to understand the nutrient budget of the Lake, particularly the potential for nutrient inflows from Drain M. It is recommended that these efforts are continued.

It is considered that the water quality and ecology of the Lake can be improved through the following means:

- Improved connectivity of the Lake with Rivoli Bay
- Maintaining the water levels within the target ranges set by the Lake George Management Committee (which are considered appropriate based on review of the available information and consultation with the Committee)
- Enhancing the supply of fresh water to the Lake system via Drain M and the interconnected drainage network.

It is recommended that a management scheme for the Lake outlet be implemented to facilitate improved connection between the Lake and the sea. This would improve the ability for the Lake to meet the required water level targets, improve the ecology, water quality and recreational amenity of the Lake, potentially restore the commercial fishery and reduce the frequency of dredging required to keep the outlet channel clear of sand. The design of the recommended management scheme has been documented herein.

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Appendix 1 – Escoffier Analysis

Appendix 2 – Concept design of groyne extension