Lake Wellington Salinity: Investigation of Management Options

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Abstract: *The salinity regime in Lake Wellington depends on the relative contributions of freshwater from rivers, removal of freshwater water via evaporation and addition of saline water from Lake Victoria via McLennan Strait. At times of low inflows from rivers, salt is transported to Lake Wellington via McLennan Strait and salinity in Lake Wellington increases. The complex nature and combination of factors that influence salinity in Lake Wellington and the fringing wetlands requires a range of management options to achieve desired conditions. Management solutions, such as providing specific inflows to wetlands and constructing several smaller barriers to increase control of saline waters either at the wetlands or in McLennan Strait, is likely to be the answer to reducing the rate of change as well as protecting those areas of greatest ecological value.*

Keywords: *Gippsland Lakes, Lake Wellington, salinity, estuarine processes.*

1. INTRODUCTION

Lake Wellington is the shallowest of the Gippsland Lakes and is generally not stratified as it is well mixed by the effects of wind. The lake is fed by the Latrobe, Thomson, Macalister and Avon Rivers and linked to Lake Victoria via McLennan Strait. Volume of the Lake is 414 GL, surface area 148 km^2 and average depth 2.8 m (Figure 1).

There is a long history of concern about the salinity regime of Lake Wellington. The simplistic view is that Lake Wellington once contained fresh water, and since the establishment of the artificial entrance to the Gippsland Lakes in 1889, is becoming increasingly saline. In fact, the salinity regime in Lake Wellington depends on the relative contributions of freshwater from rivers, removal of freshwater water via evaporation and addition of saline water from Lake Victoria via McLennan Strait. In recent years there has been a trend of increasing salinity that is driven by a reduction in freshwater inflows caused by river regulation, water extraction and a drying climate (Tilleard et al. 2009).

Lake Wellington and lower parts of the inflowing rivers provide critical habitat for a range of important estuarine dependent bird and fish species, including Black Bream (Ecos 2008). Almost all of the Gippsland Lakes is recognised under the Ramsar Convention as being of international importance for its wetlands and large bird populations (Ecos 2008; SKM 2008). Lake Wellington and its fringing wetlands are the largest single component in the Ramsar site and are listed as nationally important in A *Directory of Important Wetlands in Australia*.

Although increasing salinity in Lake Wellington is seen as a problem, it also presents an opportunity, for example, lake water may become clearer and the few species that can tolerate brackish conditions may be replaced by a richer marine flora and fauna. However, increased salinity does pose a threat to the high value fringing wetlands that surround the lake (Ecos, 2008).

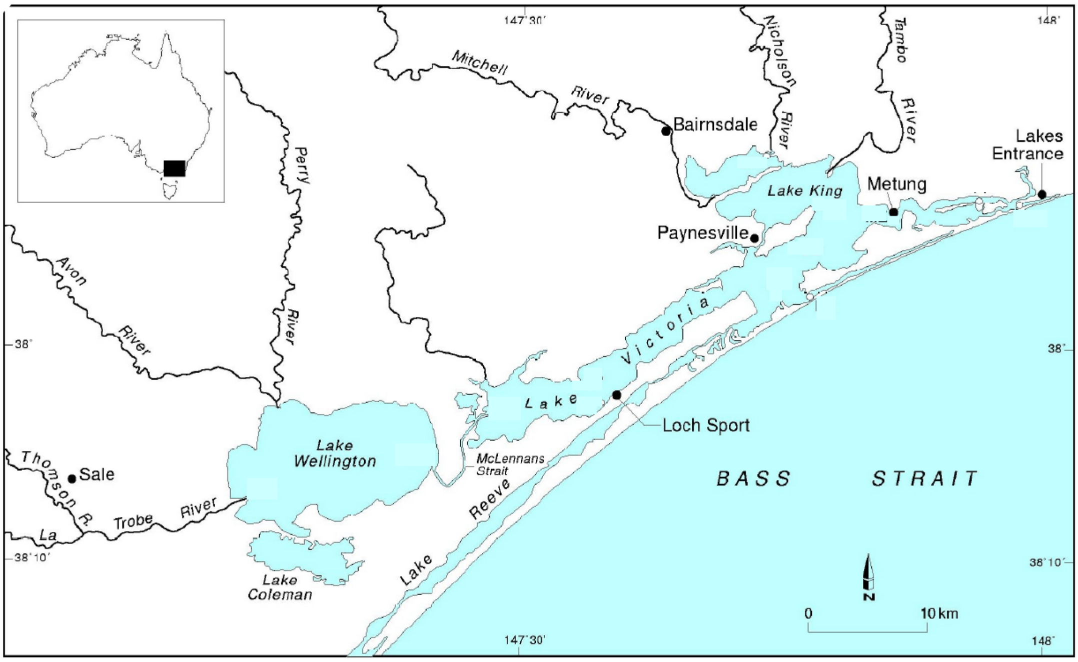

Figure 1 Lake Wellington and the Gippsland Lakes (Grayson et al., 2004)

2. THE SALINITY REGIME OF LAKE WELLINGTON

Salinity levels in the Gippsland Lakes system vary depending on relative influence of freshwater inflows from the catchment and marine water inflows through Lakes Entrance. Typically, salinity is close to seawater near the Lakes Entrance and in the eastern area of Lake King. However, during periods of low freshwater flow the salinity can be high throughout the Lakes. A wedge of highly saline water can also move many kilometres upstream into the inflowing rivers.

Focusing on Lake Wellington in particular, there are a number of factors that determine its salinity:

- Magnitude of river inflows
- Salinity of river inflows
- Salinity of Lake Victoria
- Important and export of salt to/from Lake Wellington via McLennan Strait.
- Rainfall
- Evaporation
- Groundwater interactions
- Tides
- Wind
- Ocean levels which are influenced by atmospheric pressure, wind and tides.

Prior to the opening of the permanent entrance in 1889 the Lakes were, on occasion, sealed off from the ocean in dry conditions and low salinity conditions would have prevailed in Lake Wellington and throughout the Lakes (Bek and Bruton, 1979). During these times it is likely that Lake Wellington would have been considered ‘fresh’. There would also have been occasions when the Lakes were connected to the sea, perhaps following a flood event, so Lake Wellington would have had increased salinity levels. Historical accounts confirm this with Lake Wellington being at times reported as being fresh, and on other occasions, brackish (Robinson, 1995).

Actual measured salinity levels are only available in comparatively recent times (Figure 2). Reliable, frequent salinity measurements began at Bull Bay (Site No. 226041) in 1992 and continue to the present. Average Lake Wellington salinity has a seasonal cycle with peak salinities occurring in June with lowest salinities occurring in December. In winter, freshwater inflows are usually high enough to flush salt out of Lake Wellington via McLennan Strait so salinity decreases until January when more salt water enters than leaves and salinity increases again. The actual salinity of the lake depends on the flows in a particular year and there is quite a lot of scatter around this average seasonal relationship. In particular, during dry periods, salinity can increase, for example during the 1967/68 and 1982/83 droughts.

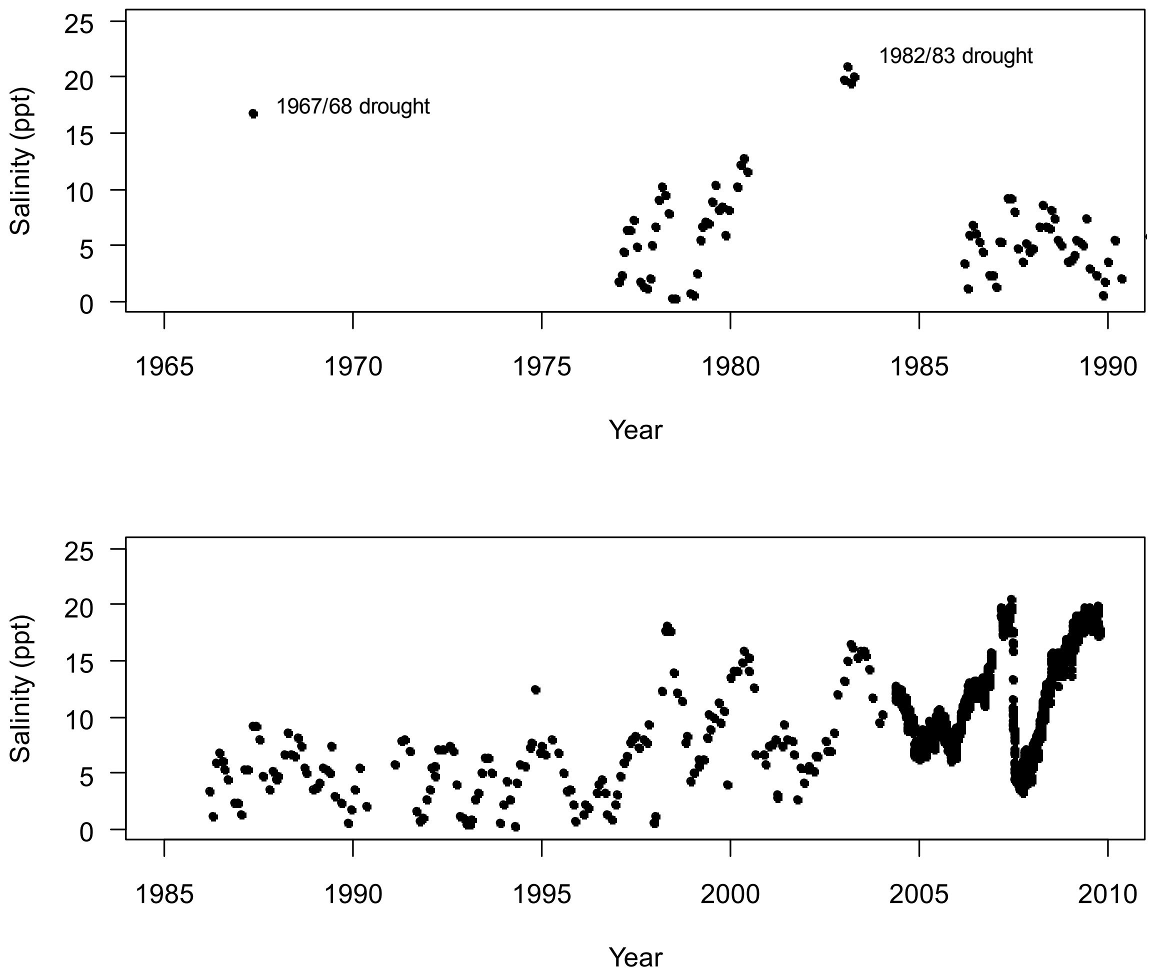

Figure 2 Measured salinity in Lake Wellington. After 1992, regular observations were made at Bull Bay (Site No. 226041); before 1992, scattered measurements are available. Frequency of observations increases after 2004.

2.1. Ecological implications of salinity regime

Most organisms have a preferred range of salinity with a major divide between 'freshwater' and 'marine' species. Freshwater is commonly defined as having salinity less than 2 to 3 ppt (although the definition varies) (Hart et al., 1991). For less tolerant freshwater species, adverse effects begin when salinity approaches 1 ppt (Hart et al., 1991) and there seems to be a critical level of salinity at about 5 to 8 ppt which corresponds to the upper limit of survival of most salinity-tolerant 'freshwater' species (Dallas and Day, 1993).

For species that are mobile, such as fish, the available habitat depends on salinity and they can respond to changes in salinity regime by shifting to different areas in the Lakes. For less mobile species, rapid changes in salinity can be a problem. For example, during the highly saline period in 2006/2007 seahorses which have a salinity tolerance of 18-35 ppt, depending on the species, were found throughout the eastern Lakes. However, large numbers were killed in late 2007 following the freshwater inflows that occurred as a result of floods (EPA, 2008). At the same time, there were reports of mussel mortality that were attributed to decreased salinity. Similarly there was substantial die-back of Phragmites and Vallisneria caused by high salinities in May 1968 that resulted from the 1967-1968 drought (Arnott, 1968; Bek and Bruton, 1979; Robinson, 1995).

3. UNDERSTANDING THE FACTORS THAT INFLUENCE SALINITY IN LAKE WELLINGTON

Although there are a larger number of factors that have the potential to influence salinity in Lake Wellington, much of the variation can be explained by considering the following variables (Grayson 2003):

- River inflows;
- Net evaporation from the lake (rainfall minus evaporation); and
- Salt inputs via McLennan Strait.

Salt transport through McLennan Strait has been assessed in a number of previous investigations (Bek and Bruton, 1979; Black & Hatton 1989, Hatton 1989, Hatton et al. 1989, Marwood 1989, Longmore 1990, Robinson 1995). These investigations demonstrated that salt water can be transferred from Lake Victoria to Lake Wellington even when there is a net outflow of water through McLennan Strait from Lake Wellington. Outflows must be larger than 130 GL/month before salt import reduces to zero. This is because dense saline water can be driven through the Strait and into Lake Wellington by tidal or wind induced currents even when fresher Lake Wellington water is flowing out near the surface of McLennan Strait. The tidal influence on the transfer of saline water affects a significant portion of the Gippsland Lakes region. While the tidal influence decreases further inland the influence is still measurable as far upstream as the lower Latrobe River.

Grayson (2003; 2006) building on earlier work by Marwood (1989) developed a computer model of Lake Wellington salinity. This has been further tested and modified for the present study to take account of very low inflows and increased data which has become available as part of work done for the Gippsland Sustainable Water Strategy. The key features of this model are:

- Salt and water transfers are based on a mass balance where the change in the storage of water and salt is calculated from the difference between the inflows and outflows to Lake Wellington;
- Water is provided by flow from rivers and is lost by evaporation. Water flows both into and out of Lake Wellington via McLennan Strait depending on the relative riverine and evaporative fluxes;
- Salt is contributed by river inflows and transfer of saline water through McLennan Strait;
- River inflow and net evaporation can be based on measured data while the salt inputs from McLennan Strait depend on a range of factors, particularly the balance between river inflows and currents within the Strait;
- During high riverine inflows (when flow out through McLennan Strait is greater than 130 GL/month), salt is flushed from Lake Wellington;
- Once outflow drops below 130 GL/month down to 0 ML/month there are additional saline inflows to Lake Wellington through McLennan Strait. Below this threshold of 130 GL/month, saline inflow was assumed to be linearly related to:
    i. Lake Wellington river outflows; and
    ii. The difference in salinity between Lake Wellington and Lake Victoria.
- Once outflow drops below zero, i.e. there is net inflow from Lake Victoria to Lake Wellington, the salt transfer to Lake Wellington is the inflow rate multiplied by the Lake Victoria salinity. In these cases, Lake Victoria salinity is assumed to be 35 ppt. This case only occurs under very dry conditions when measured Lake Victoria salinities are high (e.g. see peak Lake Victoria salinities for the 2006-2007 drought in EPA, 2008).

This modelling approach was calibrated to represent salinity in Lake Wellington during the period 1976 to 2000.

3.1. Salinity regime under future scenarios

The computer simulation model was used to examine the Lake Wellington salinity regime under a range of scenarios. Lake Wellington salinity for 1965 to 2005 was calculated for 6 cases:

1) ‘Natural’ inflows (no diversions)

2) Inflows under current level of development
3) Inflows under full level of development i.e. uptake of all extraction licenses
4) ‘Natural’ Inflows under climate change, where historical inflows were scaled to the 1997 to 2008 climate (this is referred to as Scenario D in the Gippsland Sustainable Water Strategy (DSE, 2010)
5) Inflows under climate change (scenario D) with current level of development
6) Inflows under climate change (scenario D) and full level of development.

For all cases except 4, inflows were taken from REALM modelling undertaken for Gippsland Sustainable Water Strategy. For case 4, inflows have been generated by adding back 30% of flow from case 5 to take account of the 30% of extraction that occurs under ‘current’ development. Results from this case should be considered less certain than the others.

The average occurrence of months with flows greater than 130 GL/month are shown for each scenario in Figure 3. These are the months were salt is flushed from Lake Wellington. Under natural conditions there was more than 2 months per year, on average, with these high flows, while with climate change and extractions, the frequency decreases. For the most extreme scenio (post 1997 climate change and full level of development), there is less than 1 month every 2 years where flows are high enough to prevent salt entry.

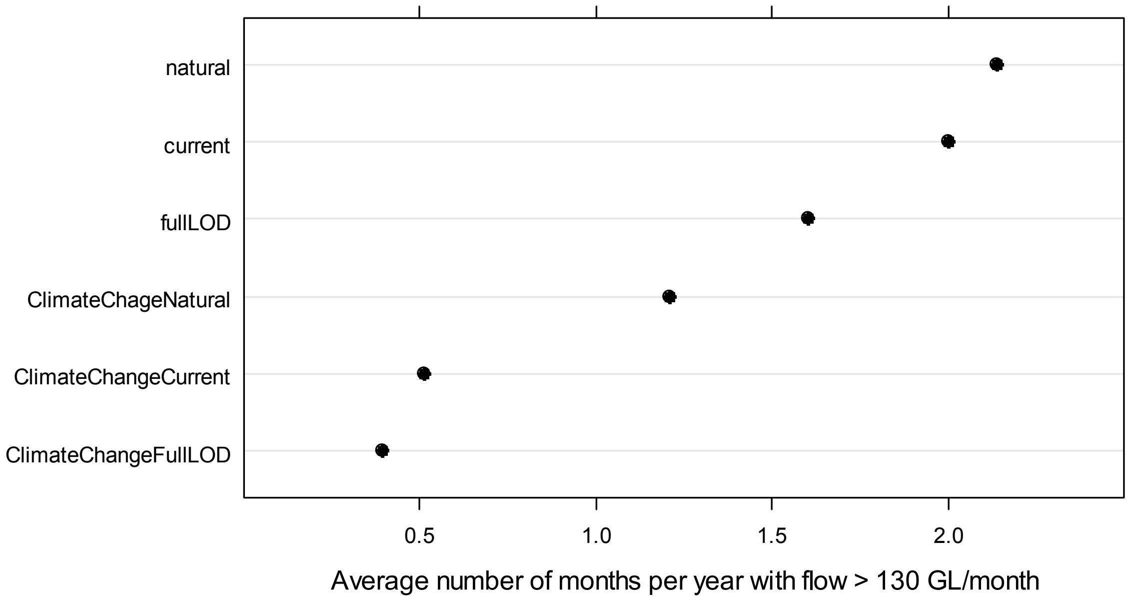

Figure 3 Salinity regime in Lake Wellington for 6 scenarios (LOD = Level of Development) (modelled data 1965-2005)

Reduced inflows mean that Lake Wellington salinity will increase. Results are summarised in Figure 4. In summary, a drying climate and increased extractions will lead to:

- Higher average salinity (as shown by increasing median salinity levels);
- A greater range in salinity (the difference between the highest and lowest Lake salinity increases as diversions increase and inflows decrease);
- Less time that Lake Wellington can be considered fresh for example for scenario 5 and 6 (post ’97 climate) there are only 2 months out of 486 where salinity is less than 3.5 ppt (2200 EC); and
- The conversion of Lake Wellington to a more marine system.

Results show that climate change (as modelled by a continuation of the 1997-2008 climate) has a major effect on Lake Wellington salinity levels. The results from scenario 4 suggests that even if there was no diversions, salinity of Lake Wellington under climate change is higher than under full development and historical climate.

In addition to the increasing salinity predicted by this modelling, there is likely to be additional increased saline imports to Lake Wellington because of sea level rise. The Victorian Coastal Strategy states that Victoria will plan for a minimum sea level rise of 0.8 metres by 2100 (VCS, 2008). To understand the full impacts of sea level rise on salt balances in the Gippsland Lakes will require separate assessment, which is yet to be undertaken. The salinity contribution of sea level rise is not considered in the modelling results within this report therefore Lake Wellington salinity under climate change scenarios are likely to be even higher then shown here.

The potential ecological implications of increasing salinity are summarised in Figure 5. As salinity increases, Lake Wellington will become more marine. This would mean an increase in marine species and loss of freshwater species. For example, there is likely to be changes in shore vegetation as species such as *Phragmites australis* are replaced by more salinity tolerant plants such as *Juncus kraussii.* There are likely to be more marine fish and fewer fresh water fish.

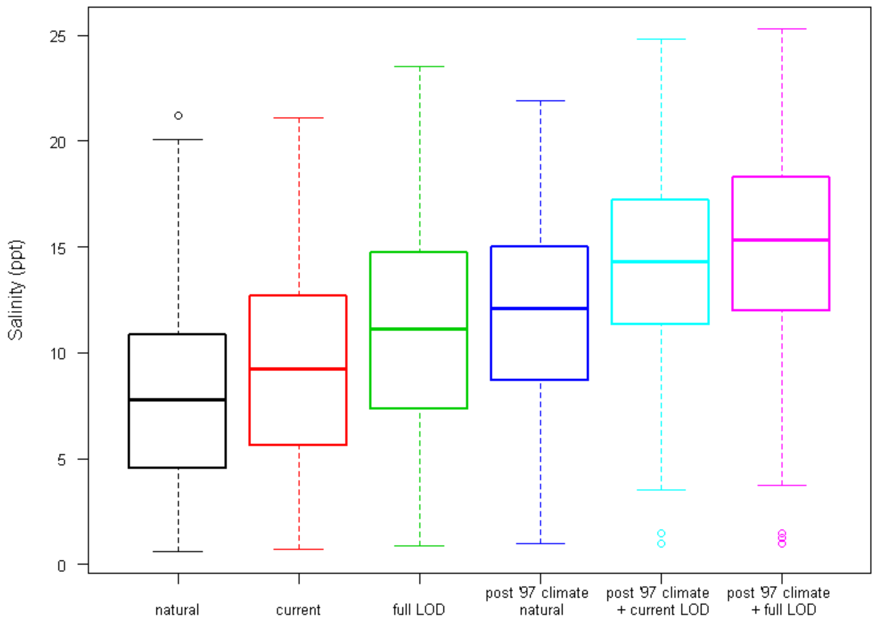

Figure 4 Salinity regime in Lake Wellington for 6 scenarios (LOD = Level of Development)

4. OPTIONS FOR MANAGING SALINITY

Without intervention, Lake Wellington is likely to become increasingly saline. If lower salinity levels are desired, consideration of the water and salinity balance for Lake Wellington suggests there are 2 main options:

1) Increase Lake Wellington outflows, to transport salt out of the Lake via McLennan Strait.
   Lake Wellington outflows depend on river inflows and net evaporation from the lake. It is probably not possible to change net evaporation so increasing river inflows may be one mechanism to manage salinity.
2) Decrease import of salt via currents in McLennan Strait once Lake Wellington outflows drop below a threshold value. It may be possible to manage salinity by decreasing these saline inputs, by constructing a partial or complete barrier across the Strait.

The magnitude of required intervention depends on the desired salinity level. For example, to make Lake Wellington fresh (less than say 2 ppt) all salt import via McLennan Strait would need to be stopped; which would require a large barrier which is estimated to cost upwards of $40 million. This cost seems difficult to justify when both historical data and modelling confirm that Lake Wellington has never been continuously fresh since the construction of the permanent entrance and even before then, would have had periods of increased salinity as confirmed by historical reports.

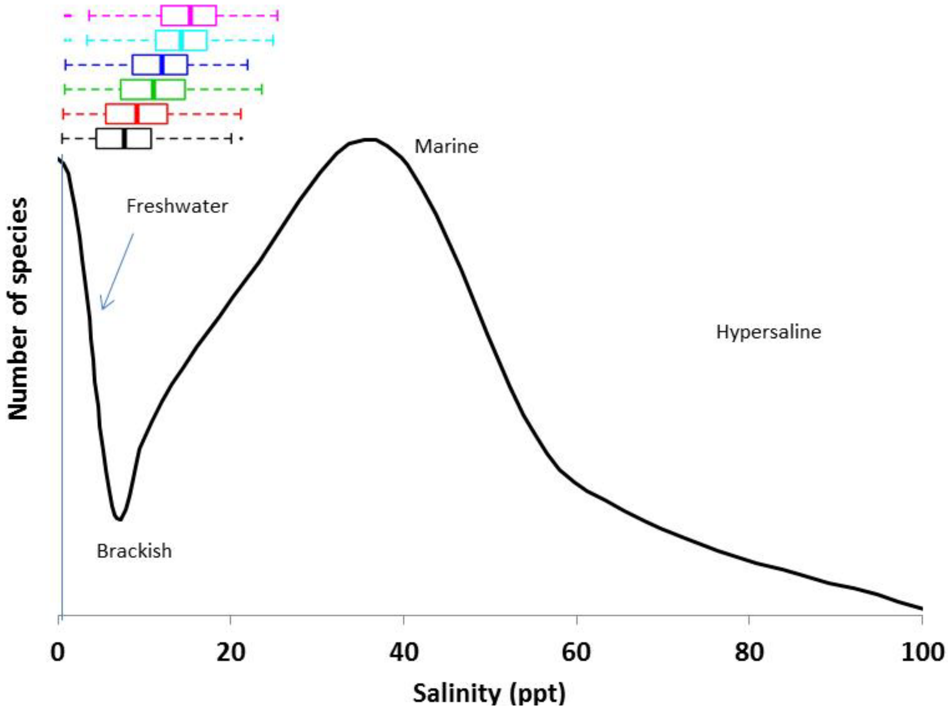

Figure 5 Lake Wellington salinity under 6 scenarios (from Figure 4) superimposed on the relationship between number of species and salinity

A partial barrier in McLennan Straight, that reduces saline inflows to Lake Wellington, could compensate for decreased riverine inflows and maintain a similar salinity regime as has occurred over the past century. Alternatively, it may be more cost effective to just manage salinity in those areas where increased salinity is likely to have the largest ecological effect, namely the fringing wetlands. It is likely to be possible to manage wetland salinity with purpose built structures and water allocations (Tilleard and Ladson, 2010). Management options are summarised in Table 1.

Table 1 Summary of management options

No	Management Option	Effect on Lake Wellington Salinity	Comment
1	Do nothing	Further increases in median salinity and variability	Lake Wellington will become increasingly Marine. Fringing wetlands will be threatened
2	Increase freshwater inflows	Likely to move salinity regime closer to natural conditions i.e. reduce median salinity and decrease variability. Provides some protection of current wetland values	Not robust to climate change: under climate change Lake Wellington becomes increasingly saline even if water extractions are reduced
3	Construct barrier(s) in McLennan St	Salinity is reduced in magnitude and range compared to the cases without this option	Requires hydrodynamic modelling to confirm effectiveness
4	Complete barrier across McLennan St	Lake Wellington is fresh most of the time	High risk, high cost option with uncertain benefits
5	Works and flows to protect fringing wetlands	Works will not mitigate the increase in Lake Wellington salinity	Aims to protect the most valuable ecological features of the Gippsland Lakes from degradation With a much lower water requirement than option 2. Robust to climate change.

5. CONCLUSION

The complex nature and combination of factors that influence salinity in Lake Wellington and the fringing wetlands is likely to require a range of management options to achieve desired conditions. Management solutions such as providing specific inflows to wetlands and constructing several smaller barriers to increase control of saline waters is likely to be the answer to reducing the rate of change as well as protecting those areas of greatest ecological value, namely the fringing wetlands. Alternatively, a partial barrier to in McLennan Strait to decrease saline inflows from Lake Wellington could maintain the salinity regime in Lake Wellington that has existed since the opening of the artificial entrance in 1889. Further investigation is required to assess the effectiveness of this option and develop the best management strategy.

6. REFERENCES

Arnott, G. H. (1968). An ecological study of the zooplankton of the Gippsland Lakes with special reference to the Calanoidae. Science. Melbourne, Monash. (cited by Robinson, 1995).

Bek, P. and Bruton, G. (1979). Gippsland Lakes and Streams Hydrochemistry. Environmental Study Series No. 238, Environmental Studies Section, Ministry for Conservation, Victoria.

Black KP, Hatton DN (1989). Hydrodynamics and salt transport in an estuarine channel: Part 2 field data analysis. Victorian Institute of Marine Science, Melbourne.

Dallas, H. F. and Day, J. A. (1993). The effect of Water Quality Variables on Riverine Ecosystems: A review. Prepared for the Water Research Commission. Freshwater Research Unit, University of Cape Town.

DSE (2010). Gippsland Region Sustainable Water Strategy: discussion paper. Department of Sustainability and Environment.

Ecos (2008). Discussion Paper: Understanding the Environmental Water Requirements of the Gippsland Lakes System, Report prepared for the West Gippsland Catchment Management Authority.

EPA (Environment Protection Authority) (2008). Gippsland Lakes Intensive Water Quality Monitoring Program 2006-07. Report to the Gippsland Lakes Task Force. TASK RCIP-EG-0607-04.095. Publication 1241. June 2008.

Grayson R (2003). Salinity levels in Lake Wellington - modelling the effects of environmental flow scenarios, Centre for Environmental Applied Hydrology, University of Melbourne. Report to Department of Sustainability and Environment.

Grayson, R (2006). Salinity levels in Lake Wellington: Modelling of Central Sustainable Water Strategy scenarios. Report to Department of Sustainability and Environment by Catchment2Sea.

Hart, B. T., P. Bailey, R. Edwards, K. Hortle, K. James, A. McMahon, C. Meredith and K. Swadling (1991). A review of salt sensitivity of the Australian freshwater biota. Hydrobiologia 210: 105-44.

Hatton DN (1989). Hydrodynamics and salt transport in an estuarine channel: Part 3, Numerical model simulations., Victorian Institute of Marine Science, Melbourne.

Hatton DN, Black KP, Longmore AR, Colman RS (1989). Hydrodynamics and salt transport in an estuarine channel: Part 1 field data collection, Victorian Institute of Marine Science.

Longmore A (1990). Saltwater intrusion into Lake Wellington, Gippsland Lakes, Southeastern Australia: its cause, effects and control, EPA.

Marwood P (1989). Impact of stream inflow on lake Wellington salinity, Environment Protection Authority (unpublished).

Remane, A. and C. Schlieper (1971). Biology of brackish water, J. Wiley and Sons.

Robinson D (1995). Water quality and nutrient status of Lake Wellington, EPA.

Tilleard, J. W. and Ladson A. R. (2010). Understanding the environmental water requirements of the Gippsland Lakes system: Stage 2: Input to the Gippsland Region Sustainable Water Strategy, report by Moroka Pty Ltd for the East and West Gippsland Catchment.

VCS (Victorian Coastal Strategy) (2008). http://www.vcc.vic.gov.au/vcs.htm.

Webster IT, Ford PW (undated) Gippsland Lakes, Victoria, http://nest.su.se/mnode/Australia/GippslandLakes/glbud.htm.