Scientific Report

# Gippsland Lakes condition report 1990-2011

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## Executive summary

### Aim

This report examines the long term trends in water quality of the Gippsland Lakes from 1990 to 2011. It assesses water quality data against the environmental quality objectives specified in the State Environment Protection Policy, Waters of Victoria (SEPP (WoV)) schedule F3 and schedule F5, for the years 2009, 2010 and 2011. The choice of the assessment years was based on their climatic characteristics, with 2009 being a dry year, 2011 a wet year and 2010 a transition from a dry to a wet year. This report also assesses the influence of major climatic variation (or baseline shifts) on selected water quality parameters.

EPA commenced regular monitoring of the water quality at five sites within the Gippsland Lakes in 1986, measuring a suite of nutrients, water clarity, a range of algal pigments and physicochemical parameters (e.g. salinity).

Despite the large number of reports written on the condition of the Gippsland Lakes, this is the first time a full assessment of all data collected as part of the fixed sites monitoring program has been undertaken.

### Characteristics of the Gippsland Lakes

The Gippsland Lakes (the Lakes) are characterised by a strong west to east gradient in salinity, corresponding to the increasing influence of ocean waters.

Lake Wellington is separated from Lakes Victoria and King (the Eastern Lakes) by McLennans Strait. The strait limits the exchange of water between Lake Wellington and the Eastern Lakes (Lake Victoria and Lake King), acting as a barrier to saltwater flow and resulting in two distinct lake systems. Lake Wellington is a well mixed mostly freshwater system, while the Eastern Lakes are more estuarine in character and generally stratified due to salinity differences between surface and bottom waters.

The seasonal and spatial patterns of a range of water quality parameters clearly reflect this phenomenon, with levels of particulate nutrients, suspended solids, chlorophyll-*a* and silicate decreasing from Lake Wellington to the Shaving Point site, near the eastern end of Lake King. Stratification due to salinity in the Eastern Lakes also drives oxygen levels down in the bottom waters, triggering a release of dissolved nutrients from the sediments into the water column. This results in higher levels of dissolved nutrients in the deeper parts of the Eastern Lakes than in Lake Wellington, which may have negative impacts by fuelling algal growth.

### Attainment of SEPP water quality objectives

The water quality experienced in the Gippsland Lakes was good during the dry 2009 year, degraded slightly in 2010 and further in 2011. The worst water quality of all years combined was experienced at the Lake Wellington site. This clearly reflects the negative influence of catchment inflows on water quality in this system. The Gippsland Lakes act as a sink for a range of catchment inputs, mostly sediments and nutrients.

Water quality was good during the dry 2009 year, which translated into the least number of exceedences of the SEPP objectives. The wet 2011 year, however, had the highest number of exceedences, thus poorer water quality. The exceedences mainly related to particulate nutrients, sediments and dissolved oxygen. The overall increase in the number of exceedences from 2009 to 2011 was attributable to an increase in the number of exceedences of the dissolved nutrient objectives for the bottom waters of the Eastern Lakes.

Sites located close to river inputs (Lake Wellington and Lake King North) exhibited the worst water quality across all three assessed years. For the four Eastern Lakes sites (Lake Victoria, Lake King South, Lake King North and Shaving Point), the number of exceedences was higher in bottom waters than at the surface, and was primarily due to exceedences of the dissolved oxygen and dissolved phosphorus objectives. During the wet 2011 year, the bottom waters also exceeded the objectives for particulate nutrients.

Exceedences of the dissolved oxygen and dissolved phosphorus objectives are of ecological concern. Low dissolved oxygen may lead to the death of fish and/or benthic organisms, while increases in dissolved phosphorus is generally thought to promote potentially toxic blue-green algal blooms.

### Trends over time and the influence of climate

Trend analysis and baseline shifts assessment also demonstrated the influence of catchment inflows on water quality. Water quality in the Lakes generally improved during the extended period of drought (1997–2010).

This observed improvement in water quality was due to a reduction in nutrient and sediment inputs from the catchments, associated with a drastic reduction in rainfall and subsequently reduced river flows. The water was more transparent, while salinity stratification and the occurrence of low dissolved oxygen saturation levels decreased across the entire Lakes system, providing a healthier environment. Meanwhile, the salinity concentrations rose to extremely high levels in Lake Wellington, potentially threatening the characteristically fresh surrounding swamps and wetlands. Salinity was generally high across the Eastern Lakes, diminishing the likelihood for potentially toxic blue-green algal blooms to develop.

At that time of drought, the Gippsland Lakes had shifted to a more saline and transparent state, but algal productivity (dominated by marine species of algae) and nutrient levels remained high. The sediments of the Lakes, being an enormous store of nutrients, are able to sustain algal growth for long periods of time (Longmore and Roberts 2006). This illustrates the complexity of this system and touches on the fact that even if the target of reduced nutrients is met, noxious algal blooms could remain a threat for some time.

Increases in river inflows since late 2010 have brought the Gippsland Lakes back to a more ‘typical’, fresher state. This is characterised by stratification in the Eastern Lakes, and turbid, eutrophic waters across the whole Lakes system, increasing the risk of potentially toxic blue-green algal blooms.

### Current limitations and future options for water quality monitoring

Our assessment of water quality indicators against the SEPP objectives highlighted a range of shortcomings in the current SEPP policy indicators. Using the current set of objectives limits our ability to assess the condition of the Lakes or ensure that the beneficial uses are fully protected.

The key shortcomings identified were the insufficient number of water quality indicators available to suitably assess condition, the non-specific limits for surface and bottom waters, the ‘atypically’ wet conditions and the now out of date catchment land use on which the current limits are based. For example, no specific limit exists for any nutrient for the Gippsland Lakes, despite nutrient levels being one of the key threats to water quality for this system. Currently, the type of indicators included in the policy and their limits do not allow for appropriate assessment of the Gippsland Lakes against the beneficial uses and thus do not contain the appropriate action levels for protecting the Gippsland Lakes.

It would be beneficial to review and update the SEPP schedule F3, and to a lesser extent schedule F5, for the Gippsland Lakes and include a broader range of indicators which cover a wider range of threats (i.e. nutrients). Further discussion and consultation is needed to decide which indicators and limits are best suited to ensure the ongoing protection of the Gippsland Lakes’ beneficial uses.

As the release of dissolved nutrients from the sediments plays such an important role in the water quality of the Lakes, it is recommended that regular monitoring and assessment be undertaken to gain understanding of its spatial and temporal impact.

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# Gippsland Lakes condition report 1990–2011

## Introduction

Historically, the Gippsland Lakes were an intermittently open system of brackish lagoons. The opening of the entrance, reduction of freshwater inflows through dam construction and water harvesting for industries and drinking supplies, and clearing of much of the previously heavily forested catchment, have placed the Lakes under enormous pressure. Under these combined effects, the Lakes have suffered degradation reflected in the loss of some fringing wetlands, increased turbidity and recurrence of potentially toxic algal blooms.

The main purpose of this report is to evaluate the water quality of the Gippsland Lakes in response to these pressures and identify potential evidence of degradation. To do so, the main pressures impacting the Lakes are identified (chapter 1), the ability of the Lakes to cope with the different pressures is assessed (chapter 2), then water quality is compared against a set of environmental objectives for the years 2009, 2010 and 2011 (chapter 3). Those objectives have been set to protect the beneficial uses of the Lakes, such as fishing or boating, hence any exceedence indicates some uses are not fully protected and therefore some environmental degradation exists.

Assessing three years of water monitoring data from 2009 to 2011 gives a narrow, recent picture of water quality in the Gippsland Lakes. To achieve a broader picture and understand how water quality is evolving over time, trends in the data collected since 1990 are identified (chapter 4).

Finally, as the climate is constantly changing, it is also important to understand how much of an influence this has on the Gippsland Lakes' water quality and how the Lakes are reacting to different climate drivers (i.e. drought). Chapter 5 explores how the water quality of the Lakes varied between the drought period of 1997-2009 and the 2011 wet year.

# Gippsland Lakes condition report 1990–2011

## 1. Water quality in the Gippsland Lakes

The Gippsland Lakes are of immense social and economic importance to many Victorians. The continuing use of the Lakes as a focus for commercial fishing and leisure activities requires that the Lakes are managed to minimise the adverse effects of human activities. The clearing and development of much of the catchment area of the Gippsland Lakes has led to the eutrophication of the Lakes system. The consequence is a potential increase in the frequency and duration of potentially harmful algal blooms, anoxic or hypoxic events and fish deaths. Past extensive algal blooms have resulted in swimming and fishing bans and caused significant loss of revenue for the region. In 2001, the Victorian Government assembled the Gippsland Lakes Taskforce to coordinate actions aimed at restoring the health of the Gippsland Lakes. The task force subsequently developed the *Gippsland Lakes Future Directions and Actions Plan* in 2002. This plan defined priorities and outlined actions to be implemented to improve the health of the Lakes. More recently, the Gippsland Lakes Ministerial Advisory Committee was formed in 2011 to support the improvement of the health of the Lakes.

To assess the condition of a water body, data on key ecological indicators are compared to set values (objectives) which, if exceeded, indicate environmental degradation.

The primary environmental policies covering water quality in the Gippsland Lakes are schedule F3 (Waters of the Gippsland Lakes and Catchment, Victorian Government 1988) and schedule F5 (Waters of the Latrobe and Thomson River Basins and Merriman Creek Catchment, Victorian Government 1996), of the State Environment Protection Policy, Waters of Victoria (SEPP (WoV), Victorian Government 2003). The policy sets water quality objectives that are expected to protect the beneficial uses (such as the maintenance of aquatic ecosystems) of the Lakes.

To assess against the environmental quality objectives in SEPP (WoV) and its schedules, and report on the condition of the Victorian marine and estuarine environments, EPA Victoria has been conducting a water quality monitoring program in the Gippsland Lakes since 1986 as part of its statewide, fixed sites monitoring program.

Under this program, water samples have been collected at five sites (figure 1, table 1) and analysed for a suite of nutrients and phytoplankton pigments (predominantly chlorophyll-*a*), as well as physical condition indicators such as temperature, salinity, dissolved oxygen, suspended solids and water clarity (Secchi disc depth). Previous investigations have shown that the waters of the Gippsland Lakes can become salinity stratified at times (Longmore 1989b), therefore sampling was undertaken at the surface and bottom of the water column.

Specific details on the water quality indicators measured and their respective objectives in SEPP (WoV) schedules F3 and F5 can be found in appendix A. The policy divides the Lakes into several segments to account for the natural variation that occurs within the Lakes system (figure 1), and allocates different water quality objectives for each segment. To help with interpretation, an explanation of the water quality indicators is provided in appendix B.

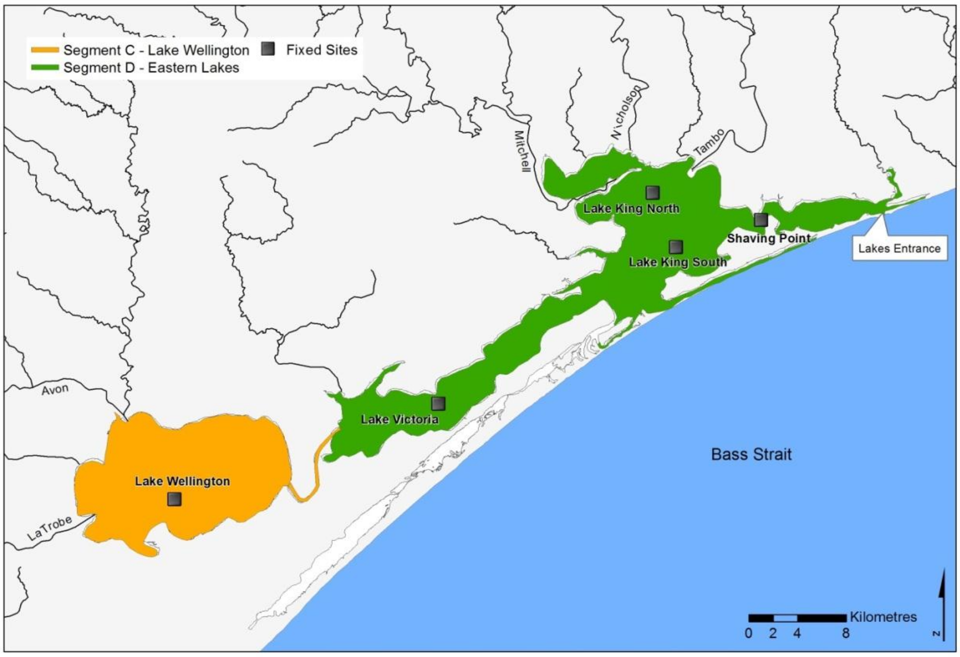

Figure 1: Fixed sites locations and SEPP segments

## Table 1: Water quality monitoring site characteristics

| Site code | Site name | Latitude | Longitude | Depth (m) |
|---|---|---|---|---|
| 2306 | Lake Wellington | 38.1066 | 147.3114 | 3.5 |
| 2311 | Lake Victoria | 38.0345 | 147.5584 | 6 |
| 2314 | Lake King South | 37.9160 | 147.7793 | 7 |
| 2316 | Lake King North | 37.8756 | 147.7573 | 7 |
| 2322 | Shaving Point | 37.9020 | 147.8542 | 15 |

This report summarises the results of water quality monitoring undertaken in the Gippsland Lakes by EPA Victoria for the years 2009, 2010 and 2011 at these five sites. It assesses trends in the attainment of SEPP (WoV) schedules F3 and F5 environmental quality objectives, long term trends for the 1990-2011 period and shifts in water quality which may be attributed to significant climatic changes (referred to as climatic baseline shifts).

### a. Key influences on the water quality of the Gippsland Lakes

The Lakes system is made up of three coastal lagoons, Lake Wellington, Lake Victoria and Lake King, that are separated from Bass Strait (ocean) by low sand dunes (figure 1). Lake Wellington is shallow and isolated from the other lakes by McLennans Strait and generally displays low salinities. Lakes Victoria and King are deeper and more estuarine in character with the influence of Bass Strait water increasing from west to east (figure 2). The physical features of the Lakes are given in table 2.

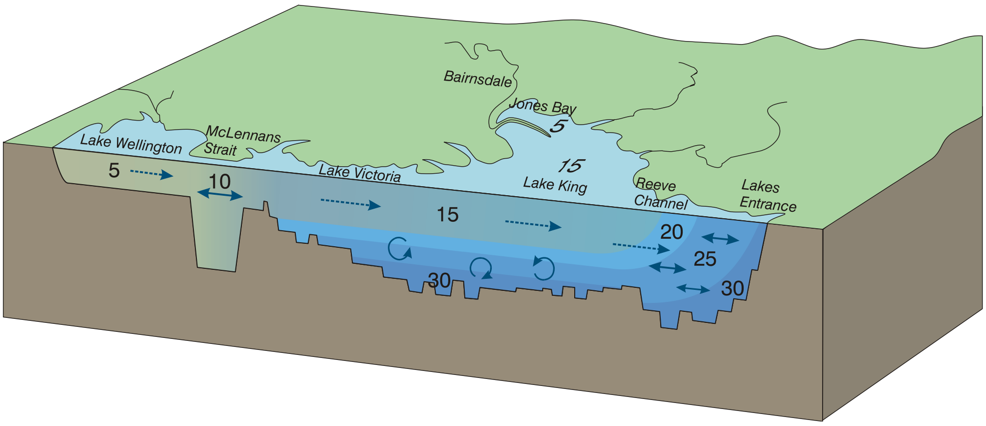

Figure 2: Conceptual model of the salinity and depth profile of the Gippsland Lakes (adapted from Parslow et al. 2001)

Before 1889 the Gippsland Lakes were connected to the sea only intermittently. The natural outlet was often closed by drifting sands, only to be re-opened when water levels were high enough to force a new entrance through the dunes (Longmore 1989b). In 1889 a narrow entrance was constructed near what is now known as Lakes Entrance and has required maintenance dredging to keep it open ever since.

Since the opening of the entrance, there has been a large number of changes to the system. Prior to the construction of the entrance, the Lakes were probably essentially a freshwater system, with marine influence limited to small areas at times of high flows when the Lakes were open to the ocean (Harris et al. 1998). Since 1950, there has been a substantial increase in the industrial and urban use of the Lakes catchment (Robinson 1995). Between the 1950s and 1980s, a number of dams were constructed on the rivers entering the Lakes. The construction of the permanent entrance, the reduction of flows due to the construction of the dams and land use change, have led to increased salinity in the system (Robinson 1995; Harris et al. 1998). Clearing of land for urban and agricultural uses has led to increased erosion and hence increased nutrient and sediment loads. This has caused the Lakes to become eutrophic (Harris et al. 1998) and as such, they experience algal blooms of varying intensity as well as fish deaths. These events have serious adverse effects on tourism and fishing.

## Table 2: Physical features of the Gippsland Lakes (Parslow et al. 2001)

| Parameter | Lake Wellington | Lake Victoria | Lake King |
|---|---|---|---|
| Catchment area ($km^2$) | 10490 | 440 | 8454 |
| Area ($km^2$) | 148 | 75 | 98 |
| Volume ($km^3$) | 0.3 | 0.36 | 0.53 |
| Mean depth (m) | 2.6 | 4.8 | 5.4 |
| Max. depth (m) | 6 | 9 | 10 |
| Water residence | 98 days | 206 days | 206 days |
| Salinity (ppt)* | 0.5-10 | 4-17 (surface)<br>7-25 (bottom) | 8-26 (surface)<br>bottom) |

*ppt: part per thousand

### b. Threats to water quality

There are a number of threats to the water quality in the Gippsland Lakes, including high nutrient loads, high sediment loads, bank erosion, decline of littoral vegetation and saline intrusion.

Nutrient and sediment loads mostly come from the five major rivers draining into the Gippsland Lakes, namely the Latrobe, Avon, Mitchell, Tambo and Nicholson Rivers, while saltwater enters the Lakes through the entrance at Lakes Entrance.

In order to mitigate these threats there have been numerous studies, reports and recommendations. For example, it is estimated that there needed to be a 40 per cent reduction in phosphorus loading to reduce chlorophyll-*a* concentrations to 8 μg/L (EPA 1996). A reduction of this magnitude would lead to a classification of Lake Wellington as mesotrophic. Another study (Robinson 1995) suggested that a 40 per cent reduction in annual nutrient loads and a 50 per cent reduction in summer and autumn nitrogen loads were appropriate targets, but Roberts et al. (2012) suggested this is too cost prohibitive to achieve.

Although the nitrogen loads of the Lakes are large compared to Port Phillip Bay, these loads do conform to the general relationship between loads and catchment area for coastal embayments in south eastern Australia (Scanes et al. 1998). In this relationship, annual loads of nitrogen increase with the size of the catchment area.

Nutrient and sediment loads estimates also have a number of other noteworthy characteristics. Firstly, there is strong inter-annual variation in the loads of nutrients (Cook et al. 2008; Davies and Martinez 2006, 2007; EPA 2008). This variation in annual loads has serious implications for the ecology of the Gippsland Lakes. For example, after a number of years of low nutrient inputs, there is a noticeable improvement in water quality parameters such as chlorophyll-*a* concentrations and water clarity. This observation has been used as evidence that if nutrient loads were reduced, there would be an improvement in water quality.

Secondly, the supply of nutrients to the Lakes through freshwater inflows is highly seasonal. Typically, river flows are low during summer and autumn and higher during winter and spring. Davies and Martinez (2006, 2007) and EPA (2008) have shown that most of the annual nutrient loading to the Lakes was delivered during storm events. For example, 99 per cent of the total nitrogen load and 83 per cent of the total phosphorus load from the Avon River, for the 2006-07 financial year, was delivered in only two storms.

It can be seen that these storm events are capable of adding large proportions of the annual nutrient loads to the system over a relatively short amount of time. Again, this has important implications for the ecology of the Gippsland Lakes as it is generally thought these large storm events are responsible for fuelling algal blooms in the Lakes (Cook et al. 2008), with impacts lasting for up to six months (Stephens et al. 2004).

In addition to river inflows, nutrients can enter the Gippsland Lakes through a variety of pathways. These include land runoff, direct precipitation, dry fallout and ground water flows. Nutrients can be added to waterways in a variety of forms. Nutrients can either be dissolved in the water or attached to particles. The nutrient load can be further subdivided into organic and inorganic fractions. The component of the total nitrogen load that is most readily available for phytoplankton growth is that in the form of ammonium and oxidised nitrogen. The component of the total phosphorus load that is most readily available to phytoplankton is dissolved inorganic phosphorus. Dissolved nutrients can also originate from the sediments. In the Gippsland Lakes, the sediment stores of nutrients are large, can be remobilised when the conditions are right and will be a significant source for decades to come (Webster and Wallace 2000). Longmore and Roberts (2006) have shown that the annual amount of dissolved nutrients released from the sediments is equivalent to between one and a half years and four years of catchment supply for ammonium and phosphate respectively.

## 2. System characteristics

### a. Stratification

Stratification occurs when a strong difference in water density exists between the surface and the bottom of the water column. While Lake Wellington appears to be well mixed and essentially fresh, the eastern part of the Gippsland Lakes is highly salinity stratified most of the time (Robinson 1995). This stratification leads to a reduction in vertical water mixing. As vertical mixing is the most important process to replenish oxygen to the bottom waters, any reduction in vertical mixing will lead to a significant decrease in the amount of dissolved oxygen available at the bottom of the water column. This phenomenon is exacerbated when the input of organic matter is increased (as in the case of the Gippsland Lakes), as decomposition of organic matter at the sediment surface is a process that consumes high amounts of oxygen.

Decrease in dissolved oxygen in bottom waters is one the most important effects of eutrophication and can lead to direct mortality of aquatic organisms if the levels are sufficiently low. It can also increase the release of nutrients by sediments. When oxygen levels are low, sediments release readily bioavailable phosphorus and nitrogen, potentially fuelling noxious algal blooms.

Figures 3 and 4 illustrate this stratification issue with a cascade effect on the dissolved oxygen level for the Lake King South site. In the August and October 2010 salinity profiles, salinity stratification exists at around 5 m deep (figure 3). The corresponding dissolved oxygen profiles show a sharp decrease in oxygen saturation at around the same depth, with both profiles decreasing to less than 80 per cent saturation (figure 4). The May and September profiles, in contrast, do not show a strong difference in either salinity or dissolved oxygen between the top and bottom of the water column (figures 3 and 4). The water column is fairly well mixed and a high amount of oxygen is available at the bottom of the water column.

Due to the wide impact salinity stratification has on water quality, the surface and bottom water sample results will be presented and analysed separately in this report.

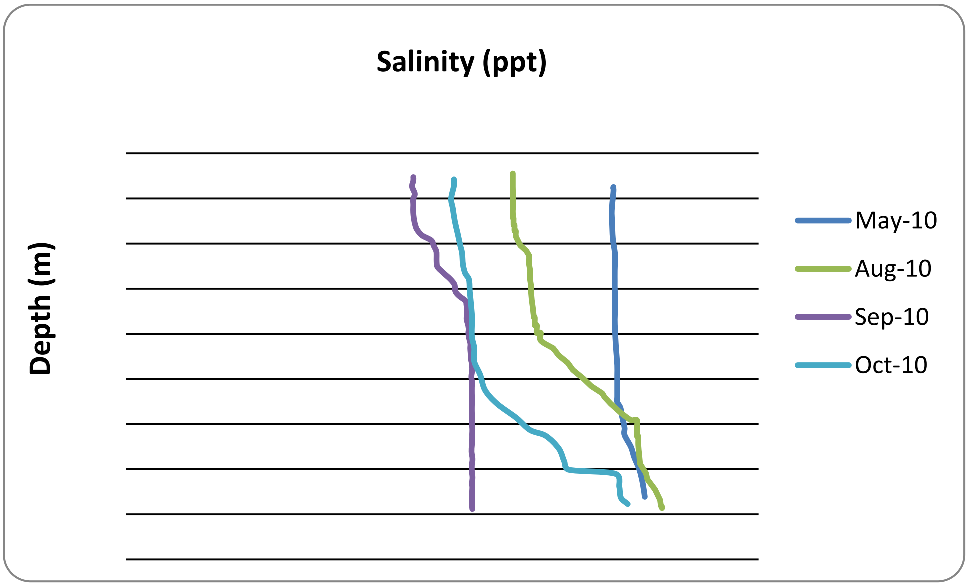

Figure 3: Salinity stratification at the Lake King South site

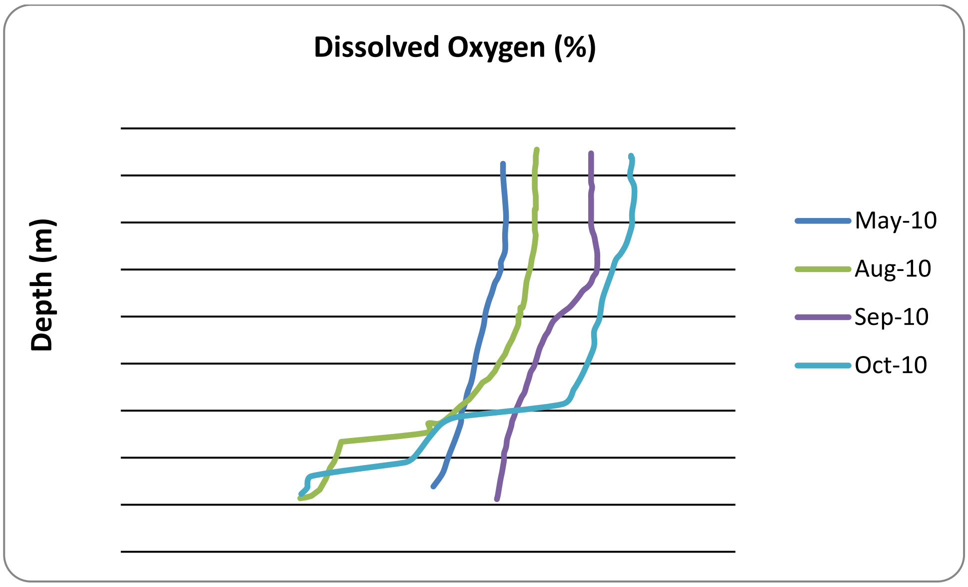

Figure 4: Effect of stratification on dissolved oxygen at the Lake King South site

### b. Site differences

The inflows to the Gippsland Lakes are characterised by a high annual variability. As such, a lot of water quality parameters will fluctuate over a wide range of concentrations, with extreme values expected, especially after flood. The resulting distribution of the data is very likely to be non-normal and medians provide a better estimation of central tendency than the means in this case. The median (and other quartiles) will be the statistics used to represent the scatter of the water quality data for the remainder of the report.

In the Gippsland Lakes, freshwater enters the system through the west (Lake Wellington) and the north east (Lake King North), while saltwater enters the Lakes through the opening at Lakes Entrance (south west). This creates a strong west-east gradient for a lot of water quality parameters, especially salinity, that are present almost all year round. This phenomenon is exacerbated by the elongated shape and orientation (mainly west east) of the Lakes themselves. Figure 5 illustrates this gradient using Underway monitoring data. Detail on the Underway monitoring program is provided in appendix C.

The Underway monitoring system consists of three different sensors and a global positioning system (GPS), and is designed to take measurements while travelling on the Lakes. Each sample being geo-referenced, the measurements taken along the transects are spatially interpolated using the Spline method to give a representation of spatial variation across the Lakes system (figure 5).

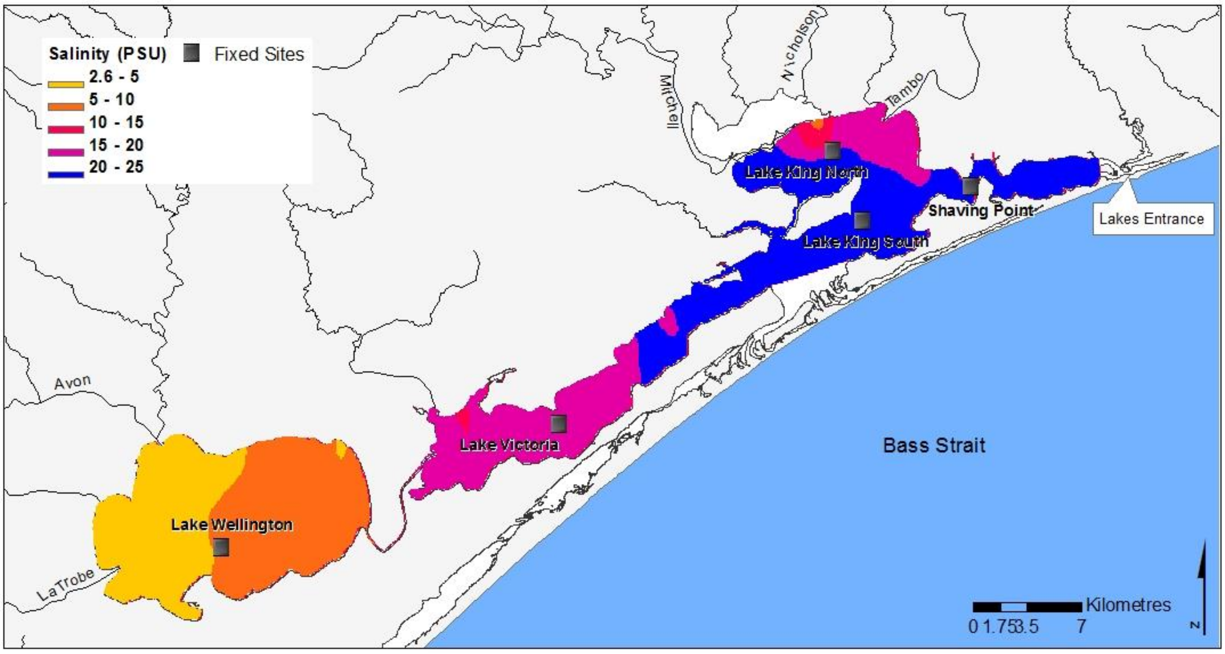

Figure 5: Spatial interpolation of salinity from Underway data (February 2011) showing a typical mostly west-east gradient in salinity produced by the large freshwater inputs to Lake Wellington and Lake King North, and the saltwater input at Lakes Entrance.

To illustrate spatial and temporal differences in water quality, the data collected is presented in the following figures as seasonal curves computed from monthly means for the period 1990-2011.

Lake Wellington is the freshest of all lakes. Salinity (figure 6) increased drastically from the Lake Wellington site to the Lake Victoria site and less markedly toward the more saline, ocean influenced Shaving Point site. The strong difference between the Lake Wellington and Lake Victoria sites is due to McLennans Strait acting as a barrier to salt water intrusion into Lake Wellington. This limited exchange of salt water from Lake Victoria to Lake Wellington also explains the strong differences that exist in the salinity range experienced at the top and the bottom of the water column at the different monitoring sites. The Lake Wellington site had a much lower range of variability between its surface and bottom waters as opposed to the other sites. This is certainly due to its morphological features (broad, flat bottom and shallow) facilitating turbulent wind mixing. Interestingly, the two Lake King sites had similar salinities both at the surface and bottom of the water column, and were much closer related than any other sites despite the distance separating them.

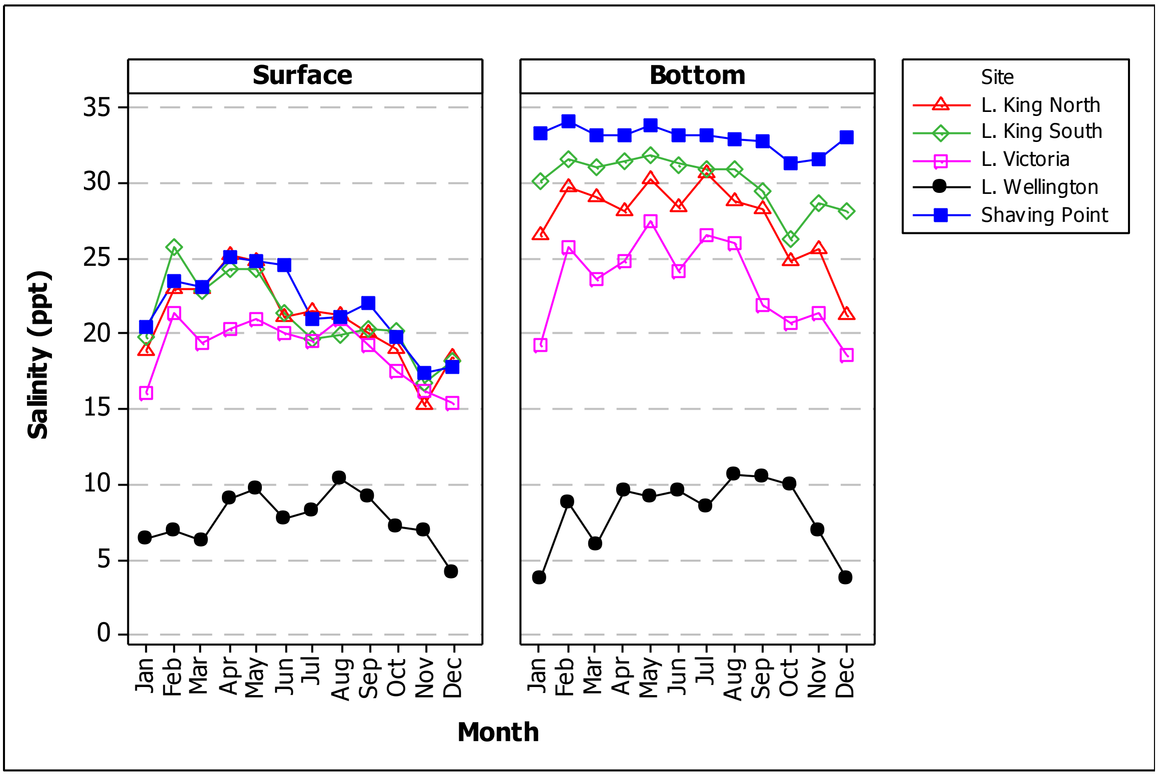

Figure 6: Monthly median of salinity

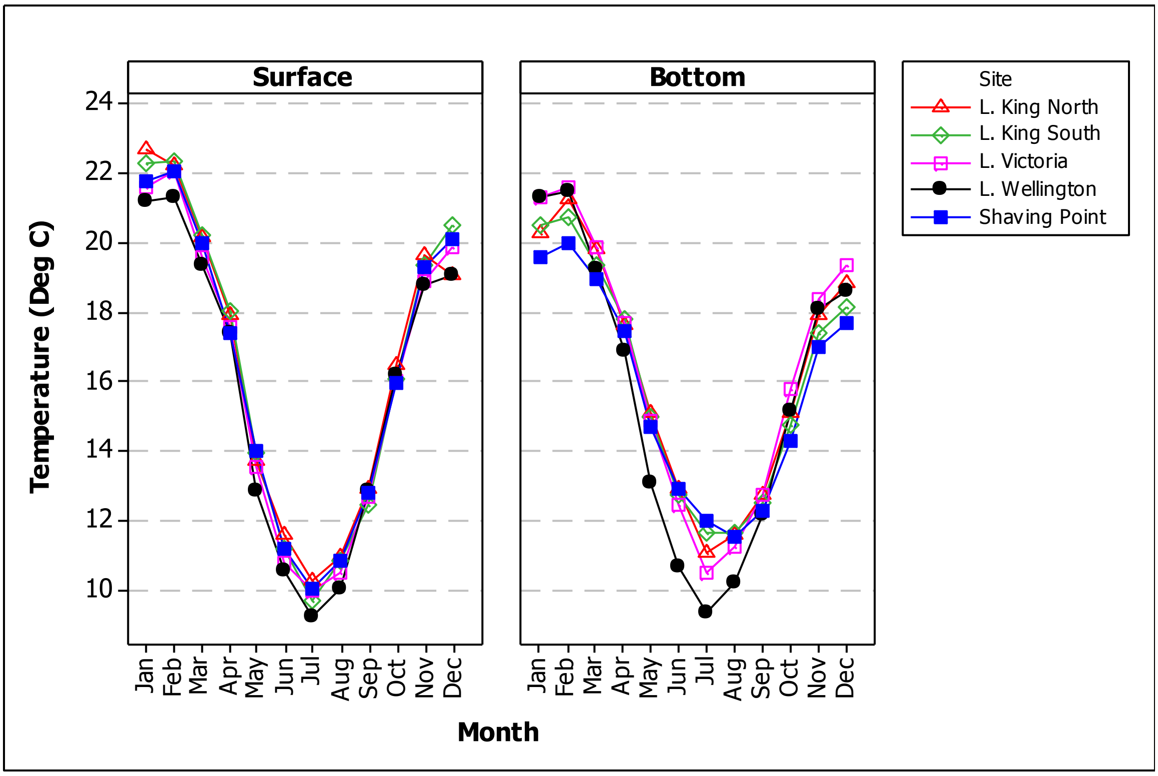

Figure 7: Monthly median of temperature

Temperature at all the sites followed a clear seasonal pattern (figure 7) with the coldest temperature recorded in winter and the highest in summer. Surface temperature at the Lake Wellington site was the coldest all year round, whereas the bottom was warmer than most sites in summer. Surface and bottom temperatures in Lake Wellington were very homogeneous due to its well mixed nature, as opposed to the Eastern Lakes. In winter, all other sites were slightly warmer than the Lake Wellington site, with bottom waters warmer than the surface due to the incursion of denser, warmer marine water, acting like a thermal buffer.

As explained earlier, the major inputs of nutrients and sediments to the Gippsland Lakes come from the rivers, thus sites located close to river mouths experience the highest concentrations of a range of water quality parameters. Conversely, sites located the furthest away will experience the lowest concentration. This results in a wide range of water quality parameters exhibiting a strong gradient based on the distance separating the monitoring sites and river mouths.

Because of the similarity in patterns of data, only an overview of the major features and patterns observed in the data will be presented here. When patterns are similar, only one graph is presented. A more detailed analysis can be found in appendix D.

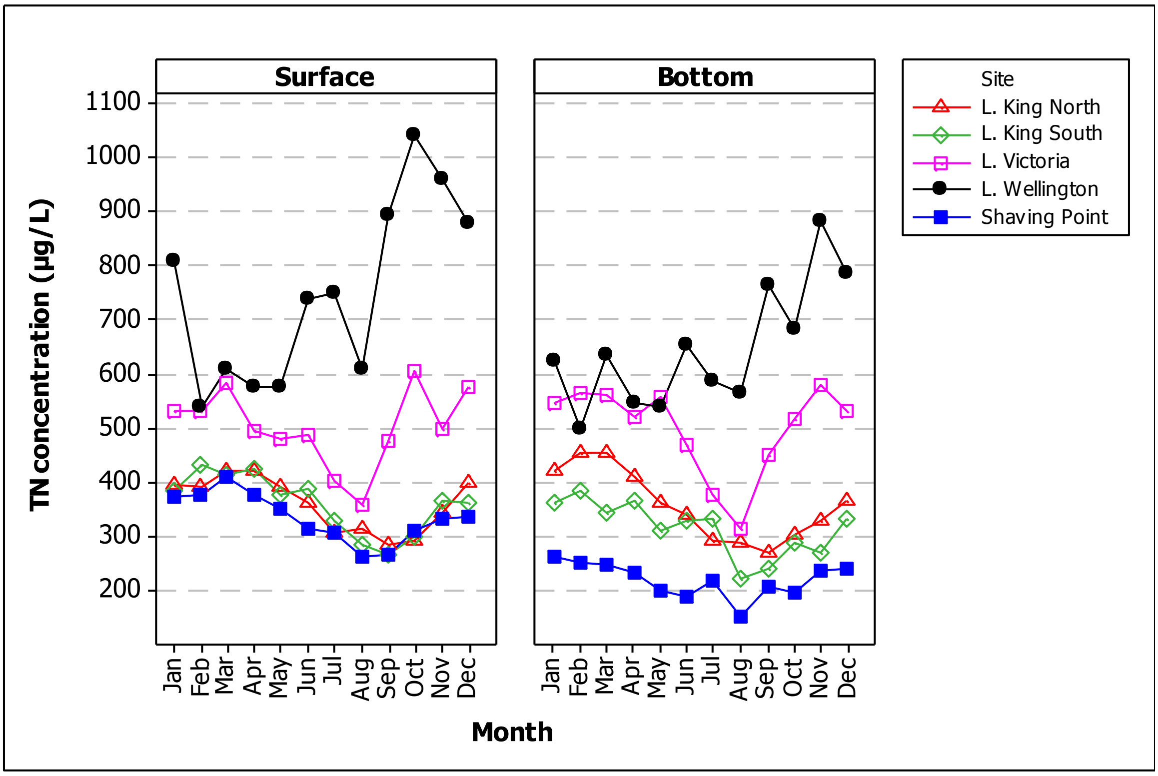

Figure 8: Monthly median of total nitrogen

Particulate nitrogen (total nitrogen (TN) and total Kjeldahl nitrogen (TKN)) and silicate concentrations were the highest all year round at the Lake Wellington site and the lowest at the Shaving Point site. Figure 8 illustrates this pattern for TN. Non-filterable residues (NFR, the amount of sediments present in the water column) and Secchi disc depth followed the same pattern and are not presented.

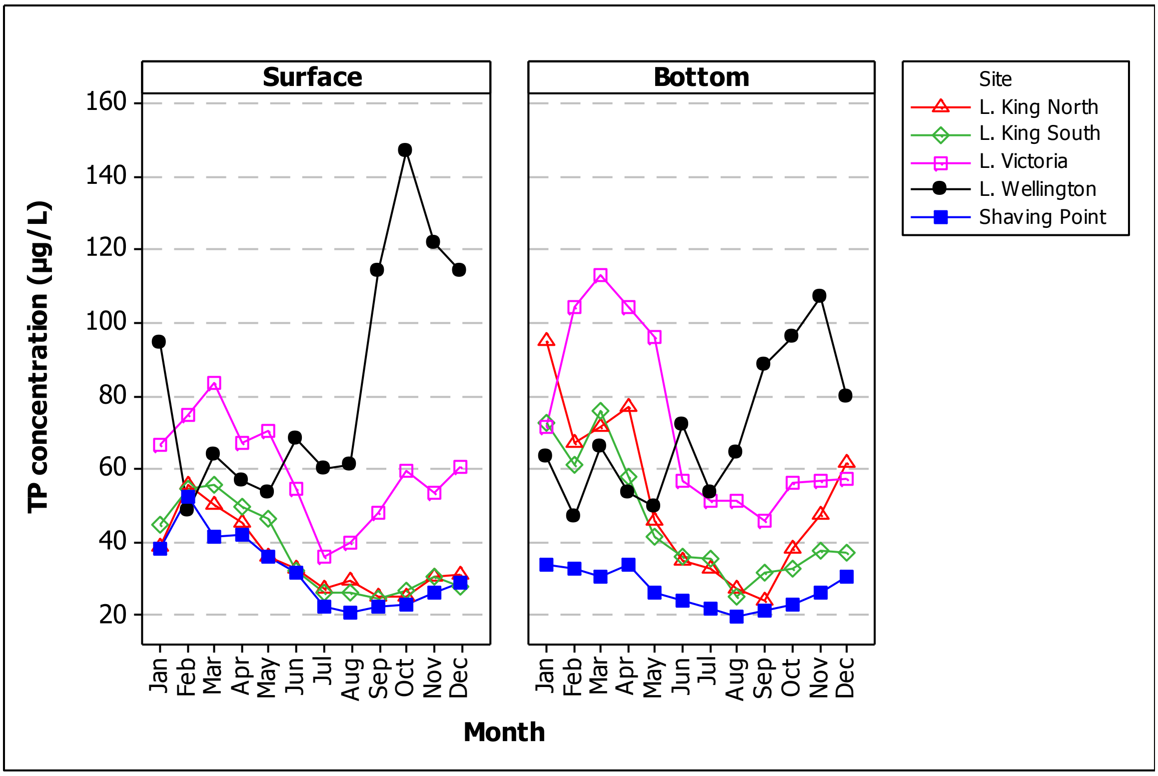

Figure 9: Monthly median of total phosphorus

Interestingly, total phosphorus (TP) generally followed the same pattern as particulate nitrogen but did not show the same behaviour during the first half of the year. During this period, the concentrations measured were higher at the Lake Victoria site than at any other sites (figure 9).

At the same time, dissolved phosphorus ($PO_4$) was extremely high, especially at the bottom of the water column (figure 10). This $PO_4$ will mix with surface waters during storms and explains the unusually high TP concentrations observed.

Dissolved nitrogen (oxidised nitrogen ($NO_x$) and ammonia ($NH_3$)) concentrations at the Lake Wellington site were very homogeneous between the top and bottom waters, while all the others sites exhibited strong increases between their bottom and surface waters. Figure 11 illustrates this point for $NH_3$. This again reflects the well mixed state of Lake Wellington, while the more stratified Eastern Lakes sites exhibited significant release of dissolved nutrients from the sediments.

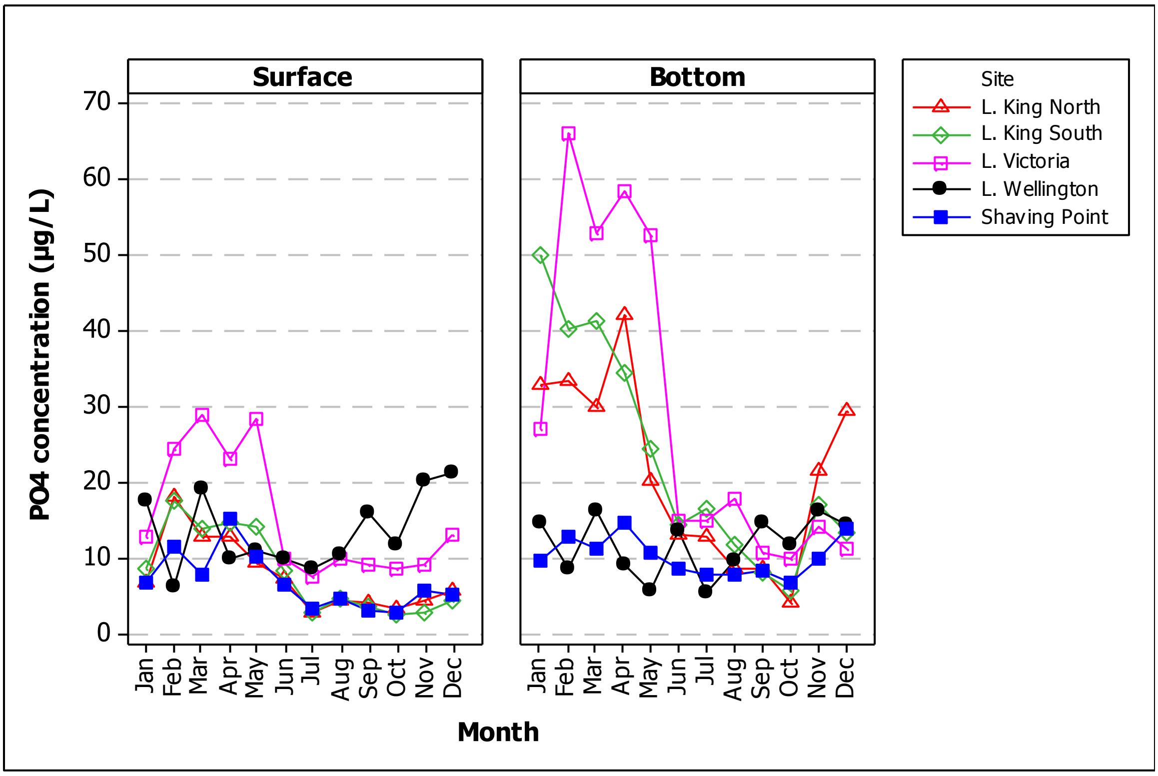

Figure 10: Monthly median of dissolved phosphorus

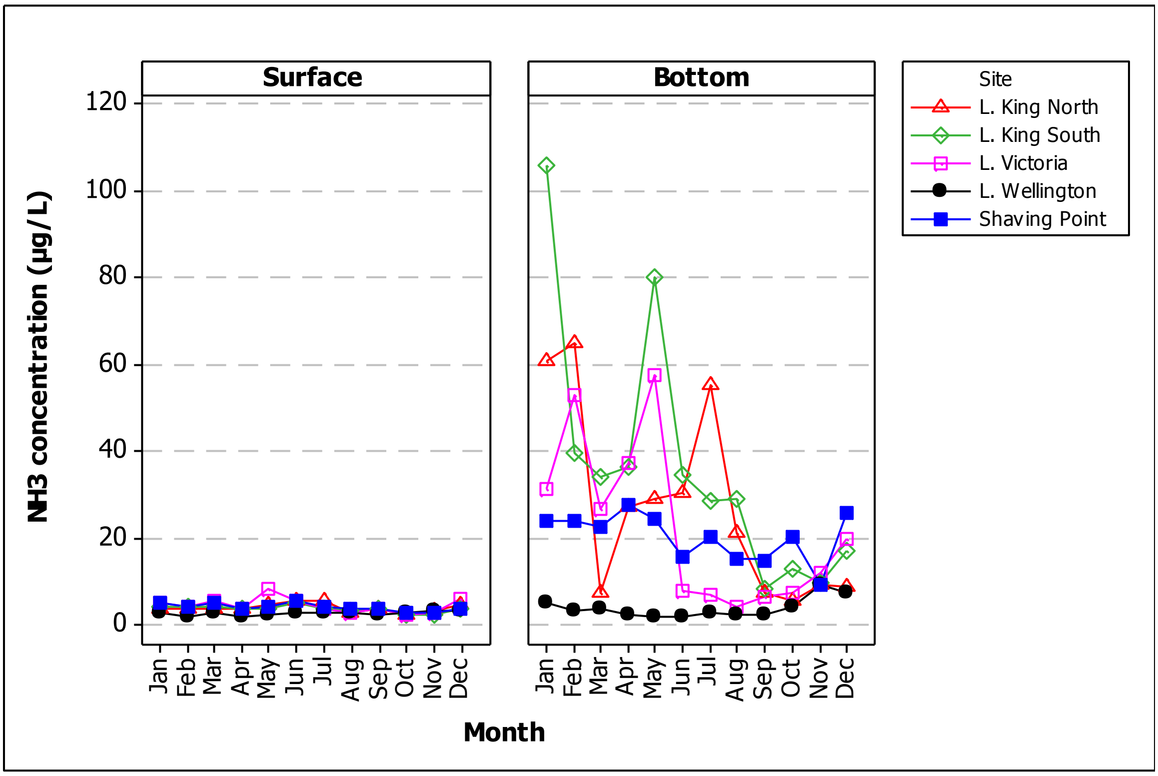

Figure 11: Monthly median of ammonia

As a result of the strong nutrient gradients noted earlier, a strong chlorophyll-*a* gradient was also observed across the Lakes system, especially in surface waters. Lake Wellington had the highest concentration and Shaving Point the lowest (figure 12).

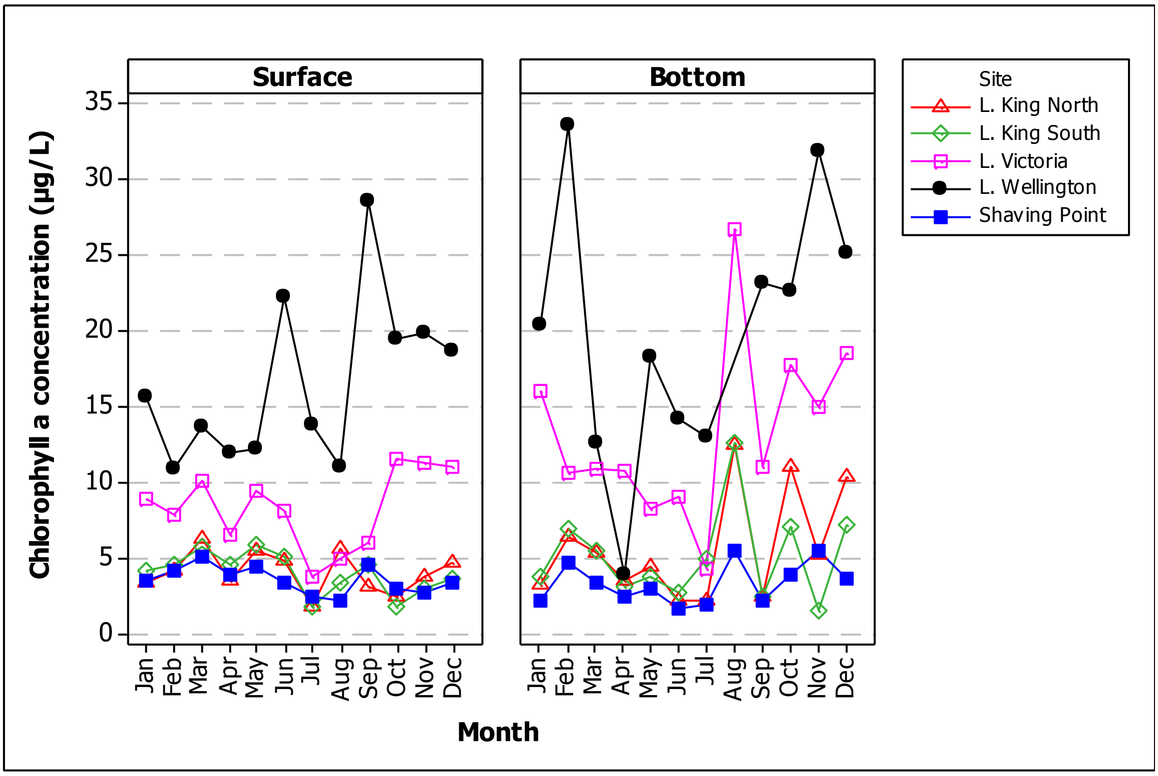

Figure 12: Monthly median of chlorophyll-*a*

Dissolved oxygen concentrations at the surface (figure 13) were around saturation (100%) at all sites, indicating that the oxygen level in the surface waters of the Gippsland Lakes was generally at a healthy level, suitable to support aquatic life. Dissolved oxygen levels in the bottom waters, in contrast, were highly variable between sites and times with all the deep sites exhibiting hypoxia from time to time.

Periods of low oxygen concentration are generally associated with a release of nutrients from the sediments and correlate well with periods of increased dissolved nutrients observed previously. Bacterial decomposition of organic matter (i.e. algae cells, detritus from catchment inputs) accumulating on the sediments will consume a lot of the oxygen. This will trigger a release of dissolved nutrients, previously bound to the sediment, to the water column. As dissolved nutrients are more readily usable by algae, any increase in their concentration can stimulate algal growth. When dying, algae will settle to the bottom, becoming part of the organic matter pool to decompose, further enhancing oxygen consumption and sustaining hypoxia.

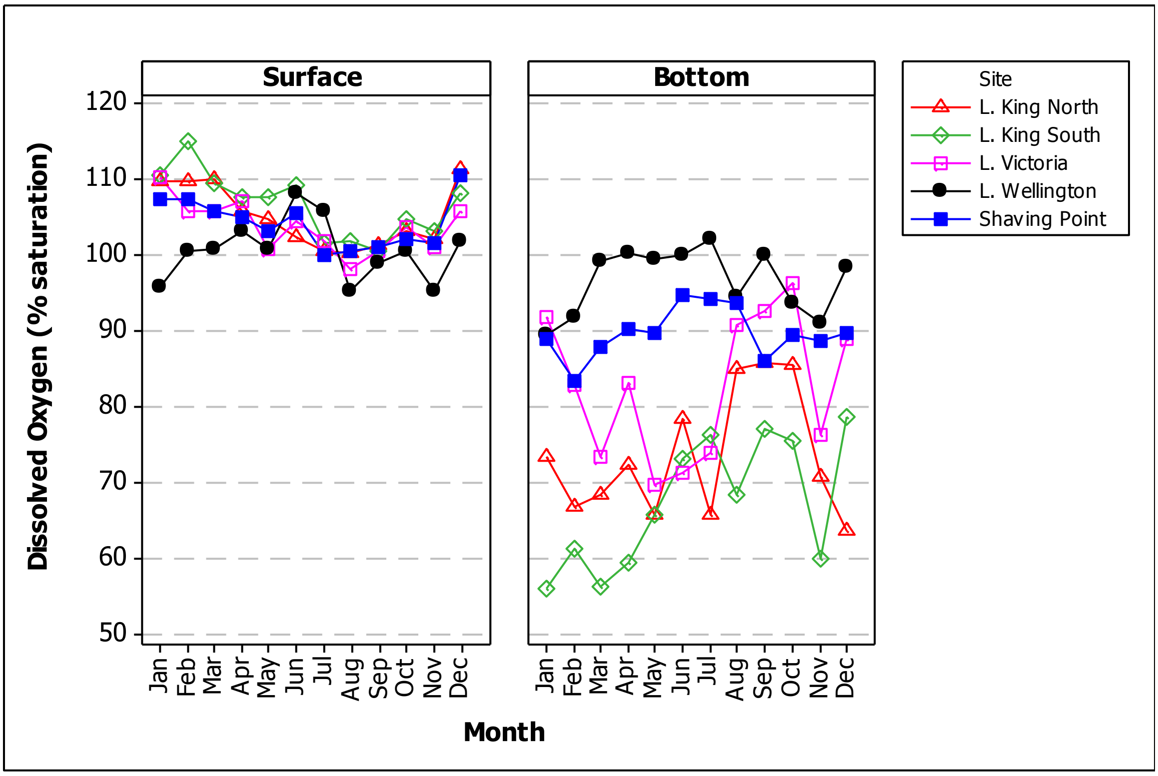

Figure 13: Monthly median of dissolved oxygen

In summary, Lake Wellington was the most eutrophic lake, with the highest concentration of nutrients and algae, but it generally did not produce the highly visible algae scums regularly affecting the rest of the Lakes. As previously explained, this is mainly due to the very turbulent and well mixed conditions in Lake Wellington. The low water residence time means that it is mainly a flow-through system with little ability to trap and store nutrients, and its water quality mainly represents the water quality of its main catchment inflow (the Latrobe River). During large floods, water spills into the surrounding wetlands and some nutrients and sediments are lost.

The Eastern Lakes, on the other hand, behave differently. They are more ocean influenced, many parts are deep and they have a high water residence time. Therefore they have a much greater capacity to trap and store sediments and nutrients. Although the water quality experienced by these lakes is generally better than Lake Wellington's, the high residence time and deep sections promoted stratification. As a consequence of this, dissolved oxygen decreased in the bottom of the water column, triggering the release of dissolved nutrients from the sediments and potentially leading to a widespread, noxious algal blooms.

## 3. Attainment of objectives specified in SEPP (Waters of Victoria) Schedule F3

Results from sampling undertaken at the five sites of the Gippsland Lakes are discussed in the following section for the attainment of water quality objectives with respect to the SEPP (WoV) schedule F3 and F5 objectives for the period 2009-2011. Long term trends are presented in the next chapter.

The primary objectives for the Gippsland Lakes are contained in SEPP (WoV) schedule F3. These objectives are based on data collected in the late 1970s by the Latrobe Valley Water and Sewage Board and assessed in Bek and Burton (1979). Water quality data was collected every month at 23 sites spread over the Lakes from the 17th of August 1976 to the 18th of July 1978, and it formed the baseline on which the water quality indicator limits and segments were set. The SEPP (WoV) schedule F3 was first implemented in 1988. It was reviewed in 2003 with the review of the overarching SEPP (WoV) legislation, although schedule F3 remained unvaried and is still a schedule of that policy. On the other hand, SEPP (WoV) schedule F5 was slightly varied during the 2003 review to better align with the rest of the policy.

Table 3 presents the SEPP (WoV) schedules F3 and F5 water quality objectives. When an indicator objective has not been specified in the policy, the Australian and New Zealand Environment Conservation Council (ANZECC, 2000) objectives apply. These have been added to table 3 when relevant.

### Table 3: SEPP schedules F3 and F5, and ANZECC objectives

| Indicator | Units | Parameter | Source | Lake Wellington | Eastern Lakes |
|---|---|---|---|---|---|
| Dissolved oxygen | mg/L | Minimum | SEPP F3 | >6 | >6 |
| | % saturation | | | >60 | >75 |
| pH | pH units | Range | SEPP F3 | 6-9 | 6.5-8.5 |
| | | Variation | | 1 | 0.5 |
| Temperature | Degree Celsius | Variation | SEPP F3 | ±2 | ±1 |
| Toxicants [1] | µg/L | Maximum | ANZECC | ANZECC | ANZECC |
| Total dissolved solids | mg/L | Annual median | SEPP F3 | 8000 | -[2] |
| Turbidity | NTU | Annual median | SEPP F3 | 15 | - |
| | | 90th percentile | | 80 | - |
| Suspended solids | mg/L | Annual median | SEPP F3 | 25 | 25 |
| | | 90th percentile | | 80 | 80 |
| Chlorophyll-*a* | µg/L | Annual median | SEPP F5 | 8 | |
| | | January-June median | | 5 | |
| Total phosphorus [1] | µg/L | Annual median | ANZECC | <30 | <30 |
| Dissolved inorganic phosphorus [1] | µg/L | Annual median | ANZECC | <5 | <5 |
| Total nitrogen [1] | µg/L | Annual median | ANZECC | <300 | <300 |
| Oxides of nitrogen [1] | µg/L | Annual median | ANZECC | <15 | <15 |

| | | | | | |
|---|---|---|---|---|---|
| Ammonium [1] | µg/L | Annual median | ANZECC | <15 | <15 |

[1] ANZECC (2000) guideline trigger values supersede schedule F3 since SEPP (WoV), 2003

[2] Management agencies in conjunction with local communities shall assess appropriate salinity objectives for the Eastern Lakes segment

### a. Data reliability

There were a total of 2084 water quality records collected over a 25 year period from EPA's marine fixed sites monitoring program. Raw data have not been reported but are available upon request.

It is important to determine the reliability of the data set and reject data that are judged to be unreliable prior to analysis. After reviewing the data collected within the fixed sites program and following discussions with analysts at the Marine and Freshwater Resources Institute (MAFRI), Department of Primary Industries, it was decided to reject all data collected prior to 1990 due to changes in analysis methods and lack of quality assurance. As such, data analysed and presented in this report extend from 1990 to 2011.

A more detailed discussion on data quality, limitations and reliability is provided in appendix C.

### b. Attainment assessment

For consistency, the approach adopted to assess attainment is the same as the one adopted for Western Port in EPA 2011. A copy of the methodology is provided in the following paragraphs.

Environmental limits are typically set either for maximum or minimum values of an indicator, or for annual statistics such as percentiles. However, laboratory measurements and calculated statistics have associated uncertainties that can often be expressed as confidence intervals. For individual laboratory measurements it is possible to use the uncertainty around the laboratory method to derive a symmetric confidence interval around each measurement, whereas for annual percentiles calculated from monthly data it is possible to use the variation among the sample values to calculate an approximate non-symmetric confidence interval for the particular percentile. These confidence intervals express the uncertainty in our ability to estimate individual values or statistics based on them.

In this report, we assessed monitoring results using a method based on an approach in Goudey (2007), to infer whether an objective was not met, using 95 per cent confidence intervals. Tables 4 to 6 summarise the results of this assessment for 2009, 2010 and 2011, for each sampling site.

A summary of the method is illustrated in figure 14, while the full methodology is presented in appendix E.

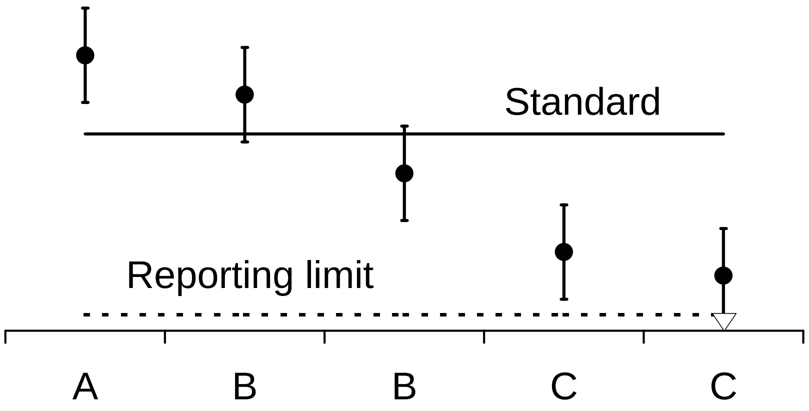

Figure 14: Interpretation of measurement interval (result ± measurement of uncertainty) against environmental standards (from Goudey, 2007)

In cases A and C in figure 14, the measurement interval is sitting entirely above (A) or below (C) the environmental objective. It is clear that the environmental standard was not met in case A (highlighted in red in tables 4 to 6), while C complied in both cases (given in black in tables 4 to 6). Complexity arises in cases B, where the measurement interval is overlapping the environmental objective. In those cases, the inference is undecided and more information needs to be considered as a basis for a decision (highlighted in orange in tables 4 to 6).

The 2009-2011 years have been chosen based on their respective characteristics. 2009 was a relatively dry year with a total inflow of 1012 GigaLitre (GL), while 2011 was a fairly wet year with a total inflow triple that of 2009 (3182 GL). 2010 was a transition year during which the 10 years long drought experienced in Victoria broke and was characterised by an inflow to the Gippsland Lakes of 1942 GL, about double the 2009 total inflow.

As explained in the previous sections, catchment inputs are the dominant source of pollutants (i.e. nutrients, sediments) to the Gippsland Lakes. Any major variation of inflow over time should therefore be reflected in the water quality of the Lakes, and it is anticipated that the number of exceedences will be greater in the wettest year (2011) and lower in the drier 2009 year.

**Surface waters assessment**

An increase in the number of exceedences in surface waters is easily seen from 2009 to 2011 (tables 4-6). In 2009, eight exceedences (and 12 instances where the assessment could not be definite due to the confidence interval) were observed. The following year, the objectives were exceeded nine times (ten instances with an overlapping confidence interval), and in 2011, the total number of exceedences reached 14 (five undefined), almost double that of 2009.

This overall increase in the number of exceedences is mainly attributable to an increase in the number of exceedences for total nitrogen (TN) and total phosphorus (TP) during the 2009 to 2011 period. In 2009 and 2010, the objective for the annual median for these parameters was only exceeded in Lake Wellington and Lake Victoria, but in 2011 the annual median objective was exceeded in surface waters at all monitored sites. In 2011, the 95 per cent confidence intervals in Lake King and at Shaving Point reached over 700 µg/L for TN and 70 µg/L for TP (more than twice the stated objective for the annual median). The increase in river flow over the 2009 to 2011 period led to an increase in nutrient inputs, resulting in an increase in the number of exceedences.

The objectives for dissolved inorganic phosphorus (DIP) were exceeded every year over the 2009 to 2011 period at the Lake Wellington site, and in 2010 and 2011 at the Lake Victoria site. DIP levels in surface waters doubled between 2009 and 2010 in Lake Wellington, reaching a 95th percentile confidence interval maxima of 51 µg/L for the annual median, then during 2011, reverting back to levels similar to those observed in 2009. In the Eastern Lakes, however, the DIP levels showed a two fold increase between 2009 and 2011, but not sufficient to exceed the stated objective. NOx and $NH_3$ levels showed a slight decrease in Lake Victoria, Lake King North and Shaving Point over the three year period.

One would expect that the increased river flow would directly impact on the amount of suspended solids entering the Lakes system, as any increase in river flow would increase sediment loads to the Lakes. However, the objectives set for the annual median and the annual 90th percentile for total suspended solids (TSS) were not exceeded, but we can note an increase in the 95 per cent confidence interval for suspended solids at all sites during the 2009-2011 period. In 2011, a year characterised by a big flood event, the annual median for TSS was only half of the stated objectives at most sites.

The impact on salinity of the increase in river flow from 2009 to 2011 is clearly observable. The annual median surface salinity in Lake Wellington decreased by 3 PSU between 2009 and 2010, with a subsequent 10 PSU decrease from 2010 to 2011, thus returning below the objective. For the rest of the Lakes, salinity decreased by 11-14 PSU at the surface during the 2009 to 2011 period.

As salinity decreased, surface chlorophyll-*a* concentrations increased between 2009-2011, with both the objectives for annual median and January to June median exceeded each year in Lake Wellington for surface waters. This demonstrates the eutrophic state of Lake Wellington, which has been exacerbated by increased river flows with high nutrient inputs from the major rivers stimulating algal growth. Meanwhile, the rest of the Lakes still showed signs of increased algal activity, with the 75th percentile for chlorophyll-*a* multiplied by up to six times between 2009 and 2011.

**Bottom waters assessment**

For the bottom waters, the objectives were exceeded 13 times in 2009 (which included Lake Wellington, but sampling of bottom waters at this site ceased in 2010, table 4). In 2010 (table 5), 12 exceedences were observed and in 2011, the current objectives were exceeded in 18 instances (table 6).

In the bottom waters, the objectives for TN, TP and DIP were exceeded every year and the objectives for $NH_3$ and $NO_x$ were sporadically exceeded. Nutrients associated with catchment inputs are mostly sediment bounded. This explains the increasing number of annual median exceedences seen for total nutrients (TN and TP), without a stepwise increase in the number of annual median exceedences for dissolved nutrients ($NO_x$, $NH_3$ and DIP). The $NH_3$ and DIP exceedences, which appeared for the first time in 2011 at the deeper sites (Lake King and Shaving Point), are certainly linked to an increase in nutrient release from bottom sediments, as corresponding exceedences only affect bottom waters.

DO levels were much lower in 2011 than in any previous years for all sites for the surface and bottom waters. Minimum bottom DO levels were lower than the SEPP objectives at Lake Victoria and both Lake King sites in 2009, but the exceedences expanded to Shaving Point in 2010, reaching levels as low as 14 per cent in Lake King North in 2011. As dissolved nutrient release from the sediments is associated with low oxygen concentration, this supports the increase in nutrient recycling observed at the bottom of the water column. The increase in organic matter-rich river inflows from 2009 to 2011, enhanced the salinity stratification at the deeper sites (Lake Victoria to Shaving Point), triggering a decrease in DO in the bottom of the water column. This in turn caused an increase in nutrient release from the sediments and ultimately an increase in the number of exceedences observed over the three year period.

As mentioned in the previous section concerning surface waters, the dramatic increase in river flow from 2009 to 2011 should be accompanied by exceedences for the TSS objective, but this was not the case. There was nonetheless a noticeable increase in the annual median values at all sites over the period.

The impact of the increase in river flow on salinity is less significant in bottom waters than it is in surface waters, with a decrease by 1 to 2 PSU only.

Finally, the Lake Wellington chlorophyll-*a* objective was exceeded every year over the assessment period in the surface waters, and in bottom waters in 2009. As bottom water monitoring stopped in 2010, it is not possible to assess this objective for 2010 or 2011. As for the remainder of the Lakes, no objective exists and therefore no assessment was possible, but chlorophyll-*a* levels have increased significantly at all sites between 2009 to 2011.

## Table 4: SEPP attainment for 2009

| | | Policy Categories | | Transparency (Secchi disc, m) | | Turbidity (NTU) | | Suspended Solids (mg/L) | | Total Nitrogen (µg/L) | | Total Phosphorus (µg/L) | | Oxides of Nitrogen (µg/L) | | Ammonium (µg/L) | | Dissolved Inorganic Phosphorus (µg/L) | | Chlorophyll-a (µg/L) | | | Salinity (PSU) | Dissolved Oxygen (mg/L) | Dissolved Oxygen (% saturation) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2009** | **Sampling Site** | SEPP segment | ANZECC Level of Protection | *Annual median* | *Annual 25th percentile* | *Annual median* | *Annual 90th percentile* | *Annual median* | *Annual 90th percentile* | *Annual median* | *Annual 75th percentile* | *Annual median* | *Annual 75th percentile* | *Annual median* | *Annual 75th percentile* | *Annual median* | *Annual 75th percentile* | *Annual median* | *Annual 75th percentile* | *Annual median* | *January - June Median* | *Annual 75th percentile* | *Annual median* | *Minimum* | *Minimum* |
| Monitoring Results Surface Waters | **Lake Wellington** | Lake Wellington | 90% | 0.5 (0.3-0.6) | 0.7 (0.5-0.8) | - | - | 21.5 (15.8-33.3) | 62.4 (33.3-96.0) | 922 (786-985) | 1014 (917-1080) | 116 (81-122) | 129 (112-148) | 0.7 (0.5-0.9) | 0.9 (0.6-1.3) | 3.3 (2.7-3.9) | 4.0 (3.3-7.2) | 20 (13-23) | 25 (19-46) | 20 (13-24) | 16 (12-20) | 24 (20-31) | 17 (14-18) | 7.5 | 89 |
| | **Lake Victoria** | Eastern Lakes | 99% | 2.0 (1.5-2.0) | 2.1 (1.7-2.5) | - | - | 4.4 (2.1-6.8) | 9.1 (5.2-9.1) | 470 (410-502) | 512 (470-551) | 42 (37-44) | 48 (42-66) | 0.8 (0.7-4.2) | 4.3 (0.8-4.6) | 4.2 (3.8-14.9) | 25.1 (4.2-37.0) | 6 (4-6) | 8 (6-9) | 6 (4-7) | 7 (4-8) | 8 (6-8) | 27 (24-28) | 7.2 | 92 |
| | **Lake King South** | Eastern Lakes | | 3.3 (2.5-4.0) | 3.9 (2.6-4.0) | - | - | 2.1 (1.2-3.9) | 20.8 (2.8-24.7) | 313 (231-398) | 403 (313-419) | 30 (17-45) | 45 (30-48) | 0.7 (0.6-0.8) | 0.9 (0.7-1.3) | 3.6 (2.6-4.3) | 4.6 (3.6-6.9) | 3 (0.4-7) | 7 (3-9) | 2 (1-3) | 3 (2-6) | 3 (2-6) | 28 (25-30) | 7.3 | 93 |
| | **Lake King North** | Eastern Lakes | | 2.5 (2.0-3.2) | 3.4 (2.5-4.0) | - | - | 2.1 (1.8-3.6) | 5.4 (2.8-6.0) | 327 (237-393) | 396 (326-407) | 31 (17-44) | 44 (30-46) | 0.8 (0.7-1.0) | 1.2 (0.8-2.7) | 3.9 (2.9-8.1) | 8.2 (3.8-13.3) | 5 (1-6) | 6 (5-8) | 3 (1-5) | 5 (3-6) | 5 (3-6) | 28 (24-30) | 7.2 | 93 |
| | **Shaving Point** | Eastern Lakes | | 3.0 (2.2-3.0) | 3.0 (3.0-3.5) | - | - | 2.5 (1.6-3.4) | 5.1 (3.4-5.8) | 332 (279-365) | 372 (332-392) | 30 (26-39) | 42 (30-46) | 1.1 (0.9-1.3) | 1.5 (1.1-1.7) | 4.4 (3.7-7.3) | 8.9 (4.4-20.5) | 4 (2-7) | 7 (4-9) | 3 (2-4) | 4 (2-5) | 4 (3-9) | 30 (26-30) | 7.1 | 94 |
| Monitoring Results Bottom Waters | **Lake Wellington** | Lake Wellington | 90% | - | - | - | - | 23.8 (13.0-36.0) | 94.4 (35.0-104.3) | 870 (795-968) | 968 (845-1327) | 106 (86-124) | 124 (101-246) | 0.9 (0.4-1.5) | 1.5 (0.8-11.5) | 3.6 (3.0-5.8) | 5.8 (3.5-8.2) | 19 (12-258) | 25 (18-60) | 18 (13-23) | 16 (13-20) | 23 (16-34) | 18 (14-19) | 7.2 | 86 |
| | **Lake Victoria** | Eastern Lakes | 99% | - | - | - | - | 3.5 (2.5-7.0) | 8.6 (7.0-8.6) | 471 (417-514) | 515 (468-697) | 44 (37-48) | 52 (43-91) | 1.3 (0.6-2.9) | 3.5 (1.3-4.9) | 6.8 (3.5-14.2) | 17 (5.0-44.8) | 6 (4-8) | 9 (6-24) | 6 (4-7) | 7 (4-11) | 8 (5-16) | 27 (24-28) | 6.5 | 73 |
| | **Lake King South** | Eastern Lakes | | - | - | - | - | 1.6 (1.1-3.6) | 5.3 (1.9-5.5) | 285 (228-322) | 322 (271-394) | 27 (19-37) | 40 (26-59) | 1.4 (0.8-1.6) | 2.3 (1.3-6.1) | 4.6 (3.2-9.6) | 10.8 (4.1-22.0) | 6 (2-7) | 8 (5-25) | 3 (2-4) | 3.7 (2-4) | 4 (3-7) | 31 (29-32) | 4.9 | 78 |
| | **Lake King North** | Eastern Lakes | | - | - | - | - | 2.1 (1.5-4.2) | 7.8 (2.6-7.9) | 301 (253-363) | 383 (288-461) | 32 (22-46) | 60 (31-119) | 1.3 (0.8-1.7) | 1.8 (1.1-4.2) | 4.5 (3.7-15.6) | 19.6 (4.2-53.8) | 8 (5-14) | 15 (8-68) | 3 (2-4) | 4 (0.6-5) | 4 (3-7) | 30(28-31) | 1.8 | 69 |
| | **Shaving Point** | Eastern Lakes | | - | - | - | - | 3.2 (2.0-5.1) | 20.4 (4.5-25.4) | 177 (164-199) | 221 (175-358) | 20 (14-25) | 26 (19-46) | 3.8 (2.9-4.2) | 4.4 (3.6-4.6) | 11.7 (7.4-12.6) | 13.1 (11.5-41.8) | 5 (3-6) | 6 (5-13) | 3 (1-3) | 3 (1-4) | 3 (3-6) | 34 (33-34) | 6.0 | 77 |

## Table 5: SEPP attainment for 2010

| | | Policy Categories | | Transparency (Secchi disc, m) | | Turbidity (NTU) | | Suspended Solids (mg/L) | | Total Nitrogen (µg/L) | | Total Phosphorus (µg/L) | | Oxides of Nitrogen (µg/L) | | Ammonium (µg/L) | | Dissolved Inorganic Phosphorus (µg/L) | | Chlorophyll-a (µg/L) | | | Salinity (PSU) | Dissolved Oxygen (mg/L) | Dissolved Oxygen (% saturation) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2010** | **Sampling Site** | SEPP segment | ANZECC Level of Protection | *Annual median* | *Annual 25th percentile* | *Annual median* | *Annual 90th percentile* | *Annual median* | *Annual 90th percentile* | *Annual median* | *Annual 75th percentile* | *Annual median* | *Annual 75th percentile* | *Annual median* | *Annual 75th percentile* | *Annual median* | *Annual 75th percentile* | *Annual median* | *Annual 75th percentile* | *Annual median* | *January - June Median* | *Annual 75th percentile* | *Annual median* | *Minimum* | *Minimum* |
| Monitoring Results Surface Waters | **Lake Wellington** | Lake Wellington | 90% | 0.4 (0.3-0.4) | 0.4 (0.4-0.6) | - | - | 33.3 (17.1-38.9) | 64.5 (37.5-66) | 1043 (937-1165) | 1171 (1039-1278) | 151 (119-182) | 186 (150-198) | 0.9 (0.8-1.2) | 1.2 (0.9-1.9) | 3.2 (2.7-4.4) | 4.4 (3.1-4.5) | 28 (16-51) | 53 (24-60) | 29 (19-37) | 33 (21-40) | 38 (29-41) | 14 (8-15) | 7.0 | 68 |
| | **Lake Victoria** | Eastern Lakes | 99% | 1 (0.5-2) | 2 (0.9-2) | - | - | 7.1 (4.6-10.7) | 16.8 (10-20.6) | 621 (490-699) | 703 (621-750) | 78 (66-95) | 97 (74-104) | 0.9 (0.6-1.3) | 1.4 (0.9-1.6) | 5.5 (2.8-6.3) | 6.3 (5.2-22.9) | 16 (10-28) | 28 (14-39) | 14 (8-17) | 10 (3-16) | 17 (14-18) | 25 (17-26) | 7.9 | 94 |
| | **Lake King South** | Eastern Lakes | | 3 (2.1-3.5) | 3.5 (2.6-4) | - | - | 2 (1.5-2.6) | 8.2 (3.1-17.8) | 305 (267-363) | 381 (305-397) | 30 (21-47) | 49 (30-57) | 0.7 (0.5-0.9) | 2.2 (0.7-4.6) | 5.0 (3.9-5.9) | 6.0 (5.0-15.3) | 5 (3-15) | 16 (5-19) | 3 (2-5) | 3 (2-5) | 5 (3-8) | 27 (20-29) | 7.3 | 90 |
| | **Lake King North** | Eastern Lakes | | 2.3 (2-2.5) | 2.5 (2.1-3.5) | - | - | 2.5 (1.4-3.8) | 6.3 (3.2-7) | 328 (269-384) | 400 (294-429) | 41 (23-51) | 58 (33-65) | 0.7 (0.6-0.9) | 1.0 (0.7-19.4) | 5.1 (2.9-5.9) | 6.1 (5.1-10.6) | 8 (0.8-15) | 16 (4-24) | 3 (3-5) | 4 (2-5) | 5 (3-11) | 27 (16-29) | 7.7 | 96 |
| | **Shaving Point** | Eastern Lakes | | 2.7 (2-3) | 3 (2.6-3.5) | - | - | 2.0 (1.2-2.6) | 3.9 (2.5-3.9) | 277 (235-312) | 315 (262-371) | 30 (19-41) | 42 (24-52) | 0.9 (0.6-1.2) | 1.2 (0.8-1.9) | 4.2 (2.7-5.8) | 5.8 (3.8-9.8) | 5 (1-12) | 12 (3-14) | 3 (2-4) | 3 (0.8-4) | 4 (3-5) | 25 (17-30) | 7.3 | 86 |
| Monitoring Results Bottom Waters | **Lake Wellington** | Lake Wellington | 90% | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | **Lake Victoria** | Eastern Lakes | 99% | - | - | - | - | 6.7 (3.5-9.1) | 11.0 (8.0-11.2) | 604 (434-632) | 647 (603-733) | 77 (61-82) | 93 (76-148) | 1.1 (0.8-2.0) | 2.3 (0.9-3.9) | 5.9 (4.7-42.1) | 44.3 (5.9-63.8) | 24 (11-30) | 36 (20-77) | 12 (8-15) | 10 (6-15) | 16 (11-29) | 26 (19-27) | 4.5 | 55 |
| | **Lake King South** | Eastern Lakes | | - | - | - | - | 1.6 (1.1-8.6) | 14.0 (7.1-14.8) | 286 (219-351) | 375(286-468) | 39 (23-65) | 66 (39-115) | 2.0 (1.0-3.5) | 3.6 (2.0-4.4) | 9.5 (5.2-13.6) | 21.2 (9.5-29.2) | 17 (4-23) | 30 (17-42) | 4 (2-6) | 9(1-27) | 12 (3-30) | 30 (26-31) | 4.0 | 51 |
| | **Lake King North** | Eastern Lakes | | - | - | - | - | 2.2 (1.4-4.2) | 24.8 (3.9-25.4) | 312 (262-349) | 359 (302-561) | 47 (30-55) | 63 (46-96) | 2.4 (0.9-4.8) | 5.1 (2.1-9.0) | 11.4 (6.6-21.1) | 21.3 (11.3-36.9) | 19 (10-21) | 21 (17-36) | 4 (2-5) | 4(2-5) | 6 (3-15) | 29 (21-30) | 4.4 | 53 |
| | **Shaving Point** | Eastern Lakes | | - | - | - | - | 5.3 (3.9-9.2) | 16.8(6.6-19.1) | 219 (159-241) | 250 (210-305) | 26 (17-33) | 36 (26-46) | 4.7 (3.1-6.4) | 7.4 (4.1-13.2) | 9.6 (6.4-16.5) | 20.7 (9.5-31.8) | 6 (3-9) | 10 (5-15) | 3 (2-4) | 3 (1-6) | 4 (2-11) | 33 (30-34) | 5.9 | 75 |

## Table 6: SEPP attainment for 2011

| | | Policy Categories | | Transparency (Secchi disc, m) | | Turbidity (NTU) | | Suspended Solids (mg/L) | | Total Nitrogen (µg/L) | | Total Phosphorus (µg/L) | | Oxides of Nitrogen (µg/L) | | Ammonium (µg/L) | | Dissolved Inorganic Phosphorus (µg/L) | | Chlorophyll-a (µg/L) | | | Salinity (PSU) | Dissolved Oxygen (mg/L) | Dissolved Oxygen (% saturation) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2011 | Sampling Site | SEPP segment | ANZECC Level of Protection | Annual median | Annual 25th percentile | Annual median | Annual 90th percentile | Annual median | Annual 90th percentile | Annual median | Annual 75th percentile | Annual median | Annual 75th percentile | Annual median | Annual 75th percentile | Annual median | Annual 75th percentile | Annual median | Annual 75th percentile | Annual median | January - June Median | Annual 75th percentile | Annual median | Minimum | Minimum |
| Monitoring Results Surface Waters | **Lake Wellington** | Lake Wellington | 90% | 0.4 (0.3-0.4) | 0.5 (0.4-0.7) | - | - | 28 (19.3-44) | 57.6 (32-62.7) | 954 (801-1069) | 1077 (954-1091) | 128 (88-142) | 144 (128-146) | 1.5 (0.8-2.3) | 3.0 (1.5-10.0) | 2.8 (1.4-3.7) | 3.9 (2.8-5.3) | 17 (9-24) | 27 (17-31) | 30 (23-42) | 26 (23-30) | 42 (30-46) | 4 (2-5) | 7.1 | 79 |
| | **Lake Victoria** | Eastern Lakes | 99% | 0.6 (0.3-0.8) | 0.9 (0.6-1) | - | - | 12.9 (9.5-24) | 72.4 (24-85.7) | 739 (673-895) | 939 (739-984) | 104 (85-131) | 136 (104-143) | 0.6 (0.5-1.1) | 1.2 (0.6-1.5) | 3.1 (2.2-4.4) | 4.8 (3.1-5.6) | 21 (10-33) | 36 (21-40) | 29 (16-45) | 20 (12-29) | 48 (29-50) | 13 (11-15) | 7.8 | 90 |
| | **Lake King South** | Eastern Lakes | | 1.1 (0.5-1.6) | 1.8 (0.7-3.5) | - | - | 6 (3.4-16) | 40.2 (10-47.7) | 450 (396-773) | 793 (442-867) | 58 (43-80) | 81 (53-88) | 0.9 (0.4-1.6) | 1.7 (0.7-2.6) | 3.6 (1.7-4.5) | 4.6 (3.1-5.3) | 9 (2 - 18) | 19 (9-37) | 15 (7-23) | 8 (4-12) | 24 (15-28) | 19 (14-20) | 7.5 | 85 |
| | **Lake King North** | Eastern Lakes | | 1.5 (0.5-2) | 2.1 (1.5-2.5) | - | - | 4.6 (2.4-11.5) | 25.6 (1.5-26.2) | 405 (307-793) | 796 (404-822) | 58 (33-76) | 76 (57-85) | 0.6 (0.3-1.2) | 1.2 (0.6-1.9) | 3.4 (0.6-4.2) | 4.3 (3.1-7.7) | 13 (4-20) | 20 (12-26) | 8 (3-25) | 5 (2-11) | 25 (5-28) | 19 (12-21) | 8.4 | 85 |
| | **Shaving Point** | Eastern Lakes | | 1.9 (0.5-2.3) | 2.5 (1.8-3) | - | - | 5.1 (2.2-10) | 19.2 (9.3-19.4) | 378 (331-762) | 769 (378-788) | 61 (35-70) | 74 (61-81) | 0.6 (0.5-1.3) | 1.5 (0.6-1.7) | 3.8 (2.0-4.7) | 4.9 (3.8-8.9) | 11 (3-16) | 17 (11-19) | 8 (3-25) | 4 (3-5) | 25 (8-31) | 19 (14-20) | 7.6 | 86 |
| Monitoring Results Bottom Waters | **Lake Wellington** | Lake Wellington | 90% | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | **Lake Victoria** | Eastern Lakes | 99% | - | - | - | - | 13 (6.8-18) | 31.4 (17.3-33) | 642 (524-919) | 927 (642-938) | 105 (78-113) | 125 (105-142) | 0.7 (0.5-2.1) | 3.6 (0.7-9.6) | 5.1(1.9-29.9) | 36.4 (5.1-43.5) | 30 (10-53) | 56 (30-59) | 17 (13-26) | 15 (12-19) | 32 (17-45) | 19 (13-21) | 1.7 | 20 |
| | **Lake King South** | Eastern Lakes | | - | - | - | - | 4.8 (2.8-11.2) | 19.9 (10.7-27.2) | 402 (291-602) | 606 (401-766) | 61 (40-76) | 77 (57-81) | 8.7 (3.8-16.2) | 20.4 (8.3-60.0) | 52.3 (29.3-86.6) | 88.7 (51.9-216.7) | 23 (5-31) | 31 (22-51) | 7 (3-14) | 4. (2-6) | 15 (7-17) | 27 (23-28) | 4.1 | 41 |
| | **Lake King North** | Eastern Lakes | | - | - | - | - | 4.3 (2.4-8) | 18.2 (6.1-20.8) | 546 (350-637) | 1276 (577-1525) | 65 (36-140) | 172 (64-254) | 9.4 (0.7-21.6) | 30.9 (7.7-46.1) | 66.1 (40.0-223.7) | 289.3 (59.2-849.1) | 20 (12-84) | 102 (12-184) | 9 (3-13) | 4 (3-8) | 15 (8-20) | 25 (24-28) | 1.1 | 14 |
| | **Shaving Point** | Eastern Lakes | | - | - | - | - | 6.3 (3.9-7.6) | 14.6(7.1-18) | 252 (175-361) | 563 (300-658) | 33 (23-46) | 47 (32-54) | 4.8 (1.1-11.2) | 11.3 (3.8-11.8) | 14.2 (3.8-23.6) | 23.6 (13.2-25.1) | 9 (3-12) | 14 (9-21) | 5 (2-10) | 2 (2-5) | 10 (5-11) | 31 (28-32) | 4.0 | 43 |

### c. Shortcomings of the current SEPP (WoV) objectives

The current policy objectives exhibit a number of shortcomings, which include:

- the period used as reference for setting the objectives
- the limited number of indicators defined in the policy
- the change of water quality threats since the time the policy was developed.

**The reference period used for setting the objectives**

As discussed in the previous chapter, the current SEPP water quality indicators (and more specifically those included in schedule F3) were set in 1988 and reviewed, but unchanged, in 2003. The objectives for the indicators were established based on data collected monthly from 1976 to 1978 at 23 sites. The data collected over this three year period was used as a baseline to determine appropriate water quality indicators for the Gippsland Lakes and to define the segments.

Unfortunately, in 1978, the Gippsland Lakes experienced their worse flood on record with a total annual flow to the Gippsland Lakes of 6195 GL (figure 15). This is almost twice the inflow of the most recent flood in 2011, characterised by an inflow of 3181 GL.

As a result, some water quality objectives were set too high in schedule F3, which results in a failure to identify key water quality threats to the Lakes. For example, in 2011, a year characterised by an important flood event, the annual median for total suspended solids was only half of the stated objectives at most sites. This indicates that some objectives may be inappropriate and set too high to be able to detect specific water quality threats.

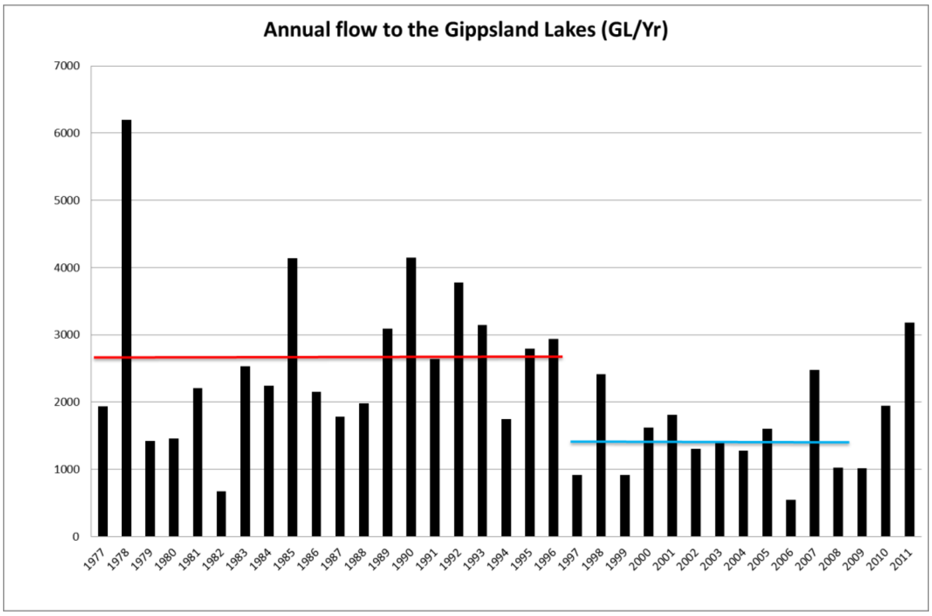

Figure 15: Total river inflow to the Gippsland Lakes (average annual flow for the period shown by red and blue lines)

**The number of indicators**

The water quality objectives present in the SEPP policy are to protect the beneficial uses of the water body they apply to. Therefore, they should align with, and provide limits for, the most important water quality threats.

For the Gippsland Lakes, these threats include sediment and nutrient loads, algal biomass and salinity for Lake Wellington.

Despite this, there is currently no specific objective for the Gippsland Lakes for any nutrients and the general ANZECC (2000) guideline for south east Australia is applied instead. Also, there is no objective for chlorophyll-*a* levels in the Eastern Lakes, which are prone to blue-green algal blooms.

In addition, the current SEPP policy does not distinguish between surface and bottom waters. The same water quality objectives apply to both. As previously demonstrated, this could be a valid approach for Lake Wellington as it is generally well mixed. Due to the stratified nature of the Eastern Lakes and the influence that stratification has on water quality, the same limits cannot be applied. Specific surface and bottom waters limits should be developed to better identify threats to the beneficial uses.

### Changes in catchment practices

Since the original policy was developed, the Gippsland Lakes and, to a greater extent, their catchment, have been modified (as discussed in section 3). Land use has changed, population and water extraction have increased and the entrance has been dredged even deeper. This has led to a more profound modification of the Lakes system from its original state. In addition, changing climatic conditions are adding extra pressure to the Lakes' integrity. Future management and policy will need to address these issues as well as community expectations of the Lakes.

The latest report on water quality in the Gippsland Lakes (Ladson and Tilleard 2011) recommends developing specific trigger levels for water quality parameters for the Gippsland Lakes and updating the SEPP schedule F3 (and to a lesser extent schedule F5) to incorporate these trigger levels. A review of SEPP schedules F3 and F5, with a view to incorporate current knowledge and indicators relevant to the current beneficial uses, would greatly help guide future management actions.

## 4. Long term trends in water quality

Long term trends in the Gippsland Lakes' water quality are presented in figures 16 to 22. Each figure is a scatterplot of all the data collected between 1990 and 2011. A locally weighted scatterplot smoother (LOWESS) curve has been super-imposed to the data to illustrate any long term trend. The LOWESS curve is obtained by fitting a line to the data using only a specified amount of the data at any one point (the tension factor). The LOWESS curve tension factor has been chosen after visual inspection of the data and fixed to 0.3. This tension factor seemed adequate to remove seasonality without masking long term variation.

Only parameters and/or sites where trends were detected are presented here. When sites showed similar trends for the same parameter, results for only one site have been illustrated.

No clear trend was detected in temperature, $NO_x$, $NH_3$ or $PO_4$. This could indicate that there are no trends in the data or a lack of sensitivity in the current monthly sampling strategy. Also, as discussed previously, sampling was less frequent in earlier years than present and this could impact on trend characterisation.

Salinity (figure 16) showed a clear upward trend at all sites for surface and bottom waters from 1990 to 2009, followed by a sharp decrease, consistent with the changes in river inflows experienced during the period.

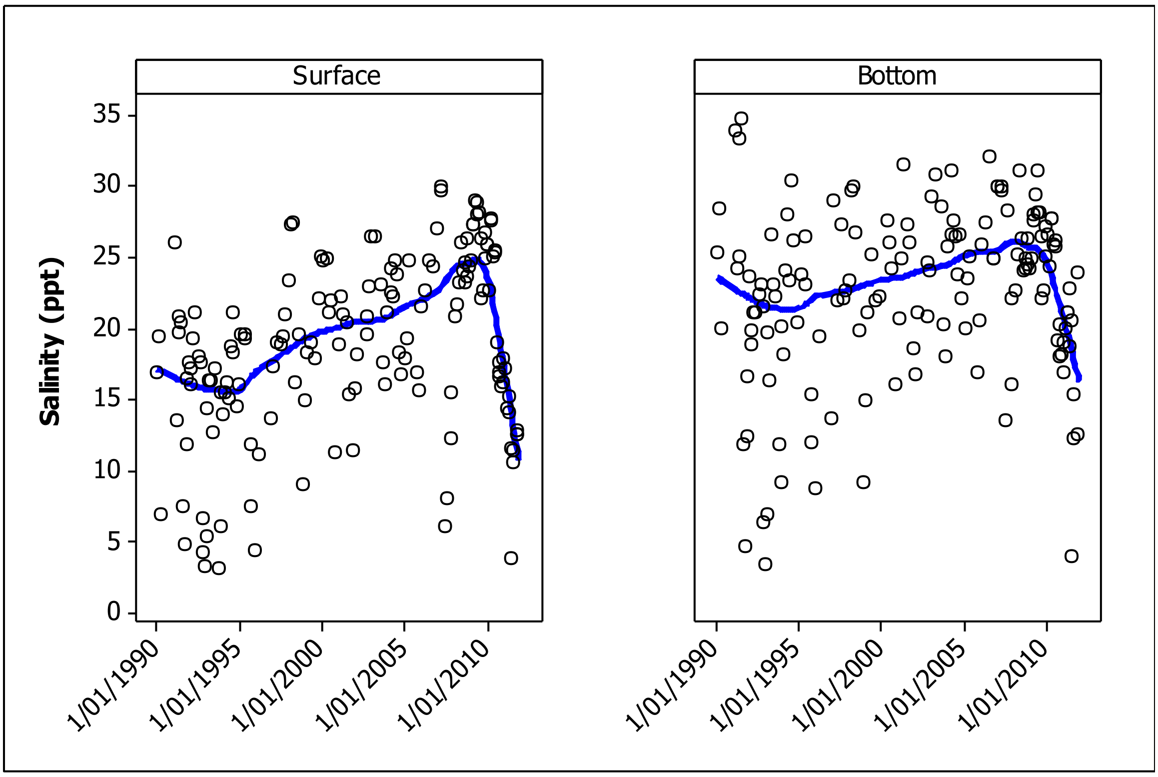

Figure 16: Salinity at the Lake Victoria site (no objective exists for salinity at this site)

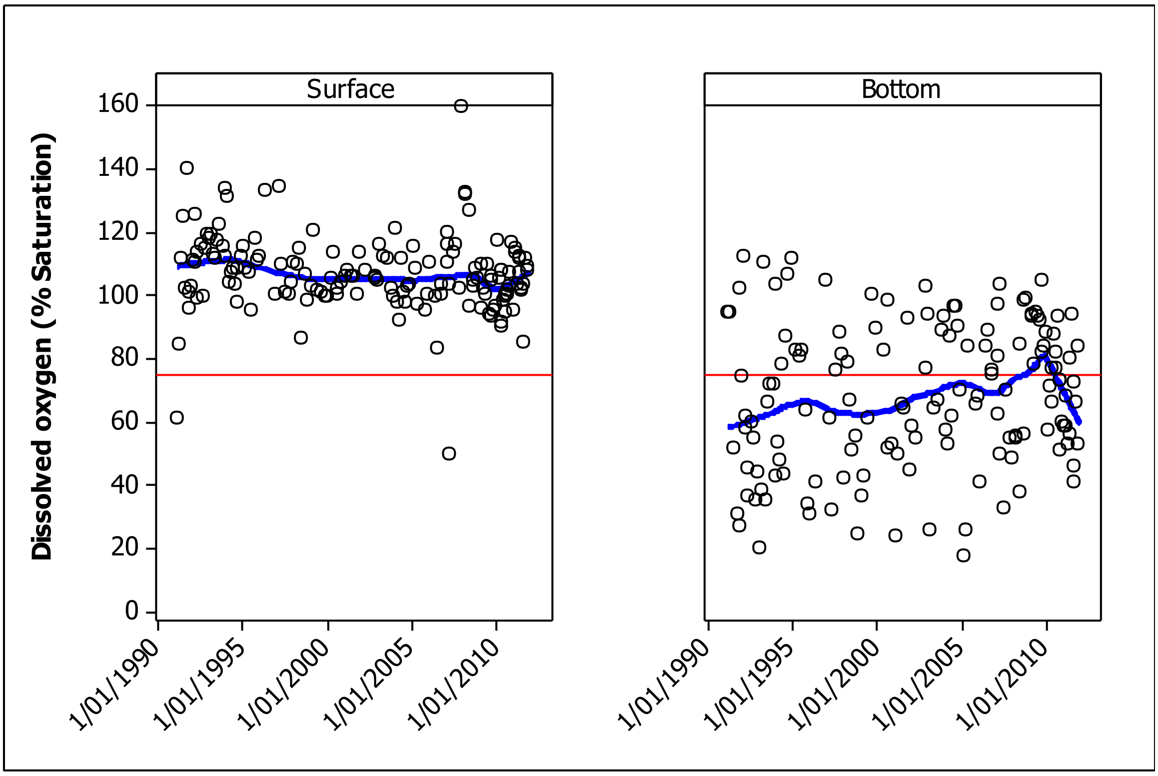

Figure 17: Dissolved oxygen at the Lake King South site (SEPP F3 objective shown in the solid red line)

Dissolved oxygen (figure 17) showed a downward trend at all sites for surface waters, with the LOWESS curve tending to 100 per cent saturation around 2006, followed by a small increase in 2007. The dissolved oxygen appeared to get back to around 100 per cent saturation prior to another increase in 2011. Bottom waters showed a similar pattern but inversed compared to the surface. The general trend is going up with two decreases in 2007 and 2011. Like salinity, the dissolved oxygen pattern observed is directly related to freshwater inflow. When river inflow is increasing, algal growth is stimulated and the oxygen level in surface waters increases to above saturation. While during a period of low flow, algae activity is reduced and oxygen levels return to equilibrium (100%). For the bottom waters, increase in inflows and algal activity will lead to an increase in consumption of oxygen during organic matter decomposition. Therefore, oxygen levels gradually increase with a decrease in river inflow and decrease when river inflow increases.

Chlorophyll-*a* (figures 18 and 19) supports this explanation with a decreasing trend (decrease in algal activity) until 2005, when concentration increased drastically until 2011, with a slight decrease around 2009. This pattern is clearly observable at Lake Wellington (figure 18) and dampened down when going east in the Lakes system. As a result, no clear trends were observed at Lake King North or at the Metung site (figure 19).

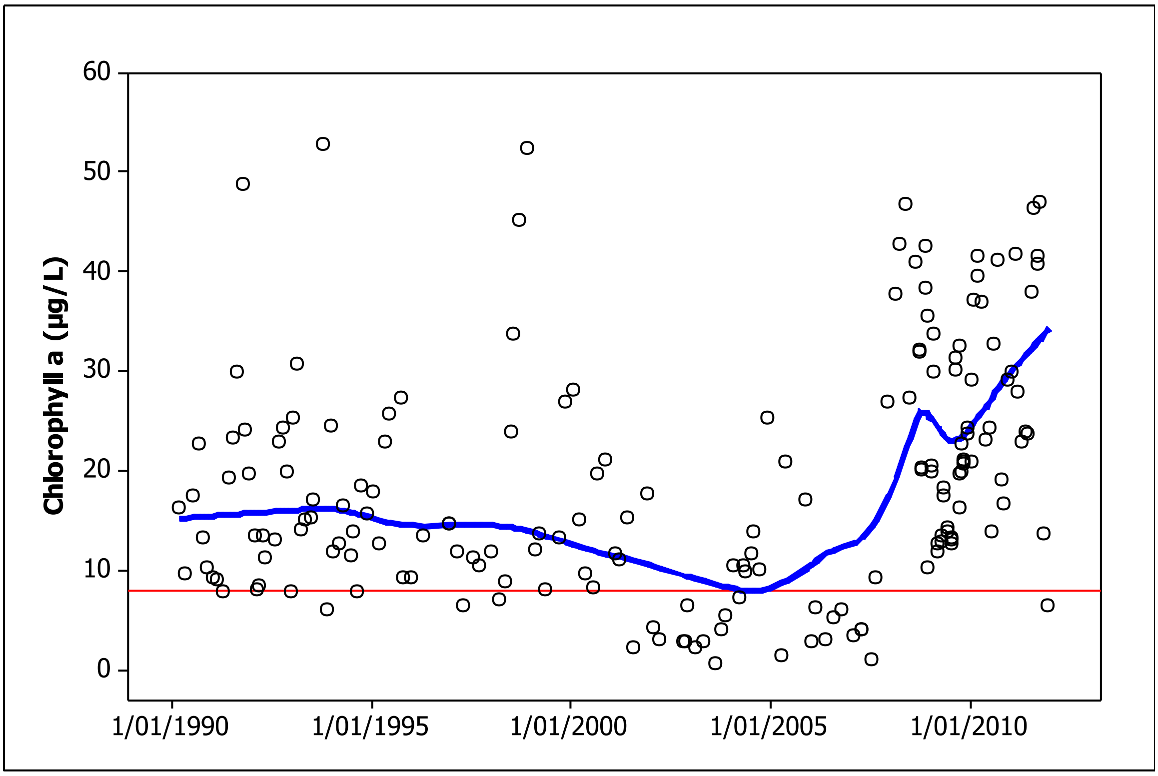

Figure 18: Chlorophyll-*a* at the Lake Wellington site for surface waters (SEPP F5 objective shown in the red solid line)

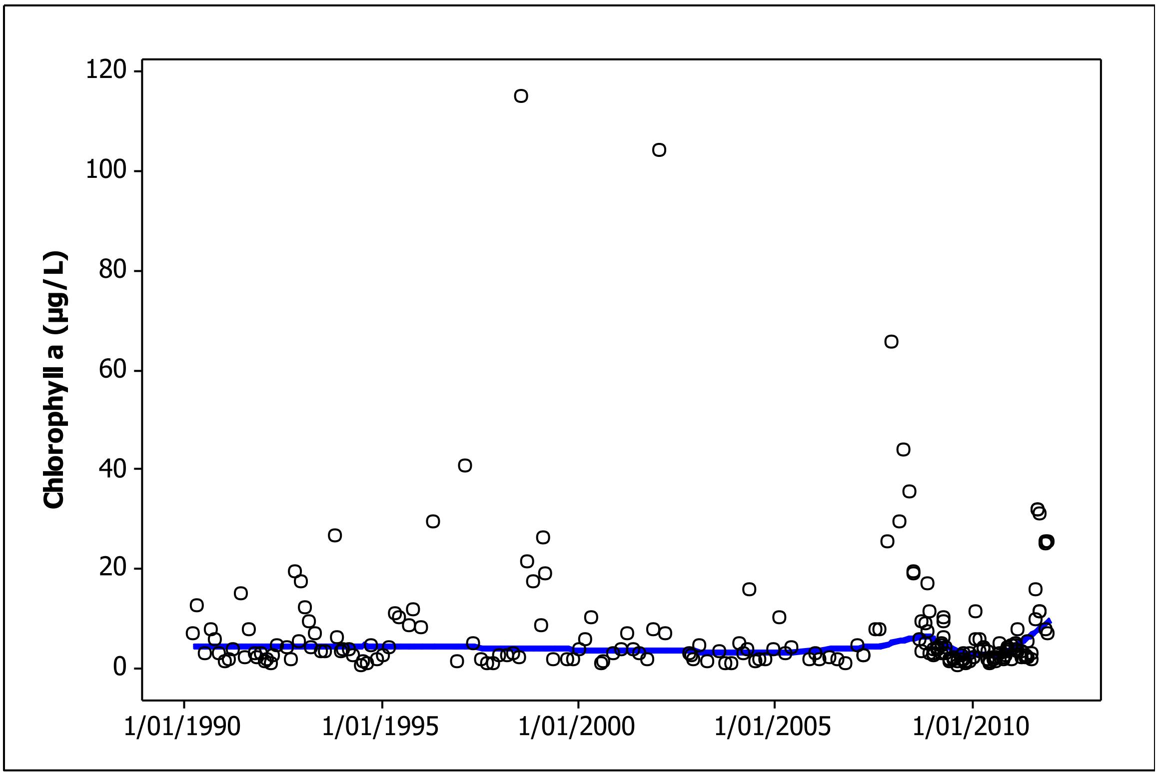

Figure 19: Chlorophyll-*a* at the Shaving Point site for surface waters (no objective exists for chlorophyll-*a* at the Shaving Point site)

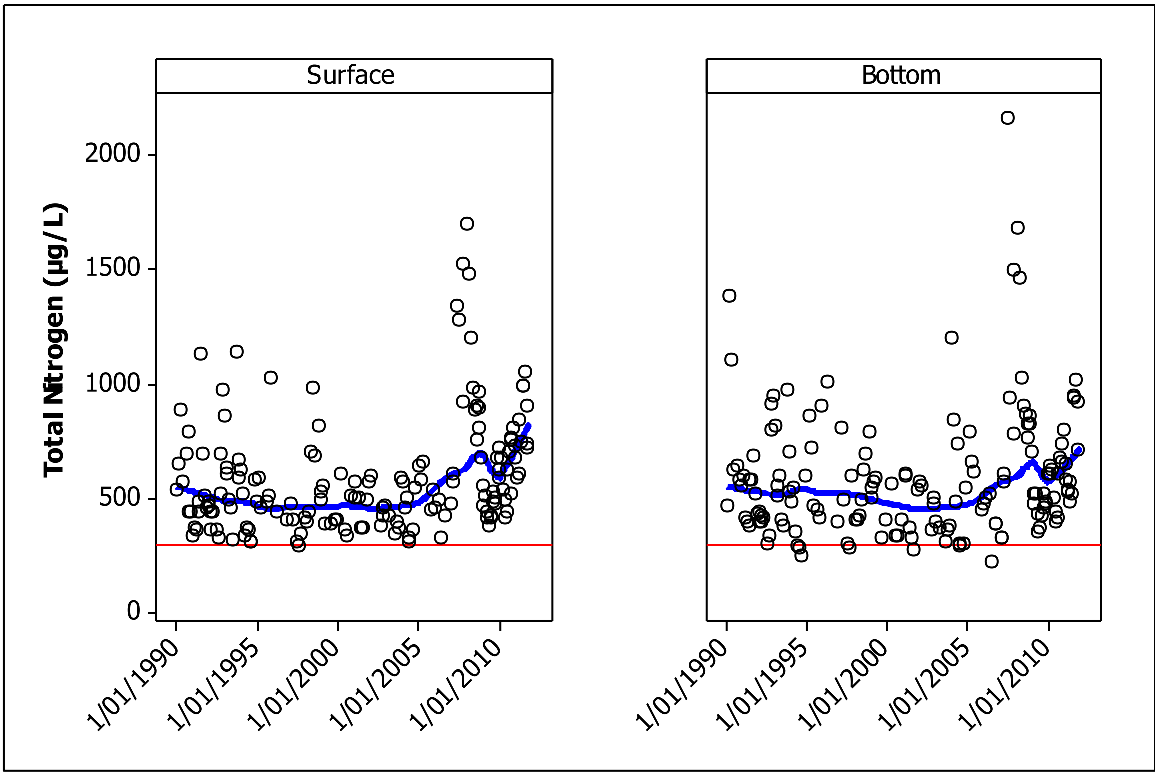

Figure 20: Total nitrogen at the Lake Victoria site (ANZECC (2000) objective shown in the red solid line)

Algal growth is regulated by suitable environmental conditions (i.e. temperature, salinity) and the availability of food (nutrients). As most of the nutrients are transported to the Lakes system by the rivers, it is expected that most nutrients will generally exhibit the same trends as chlorophyll-*a*, especially for the surface waters. This was the case for total nitrogen, total Kjeldahl nitrogen, silicate and total phosphorus, all exhibiting the same pattern as chlorophyll-*a*. Figure 20 illustrates this for total nitrogen.

In addition to nutrients, rivers are also discharging suspended sediments to the Gippsland Lakes. Changes in river flows will alter the amount of sediments present in the water column and suspended sediments concentration should follow the same pattern as nutrients. Figure 21 reflects this with non-filterable residue (NFR) concentration following the pattern and trends of most nutrients.

Secchi disc depth (figure 22) showed an increase until 2005 (when the water got clearer), followed by a strong decrease at all sites. Secchi disc depth is a measure of the amount of light penetrating the water column and is directly influenced by particles in suspension. The particles in suspension are mainly sediments but also include algal cells. As a result, the pattern of change observed in the Secchi disc depth across the Lakes system is a combination of the pattern observed in total suspended sediments (figure 21) and chlorophyll-*a* (figures 18 and 19).

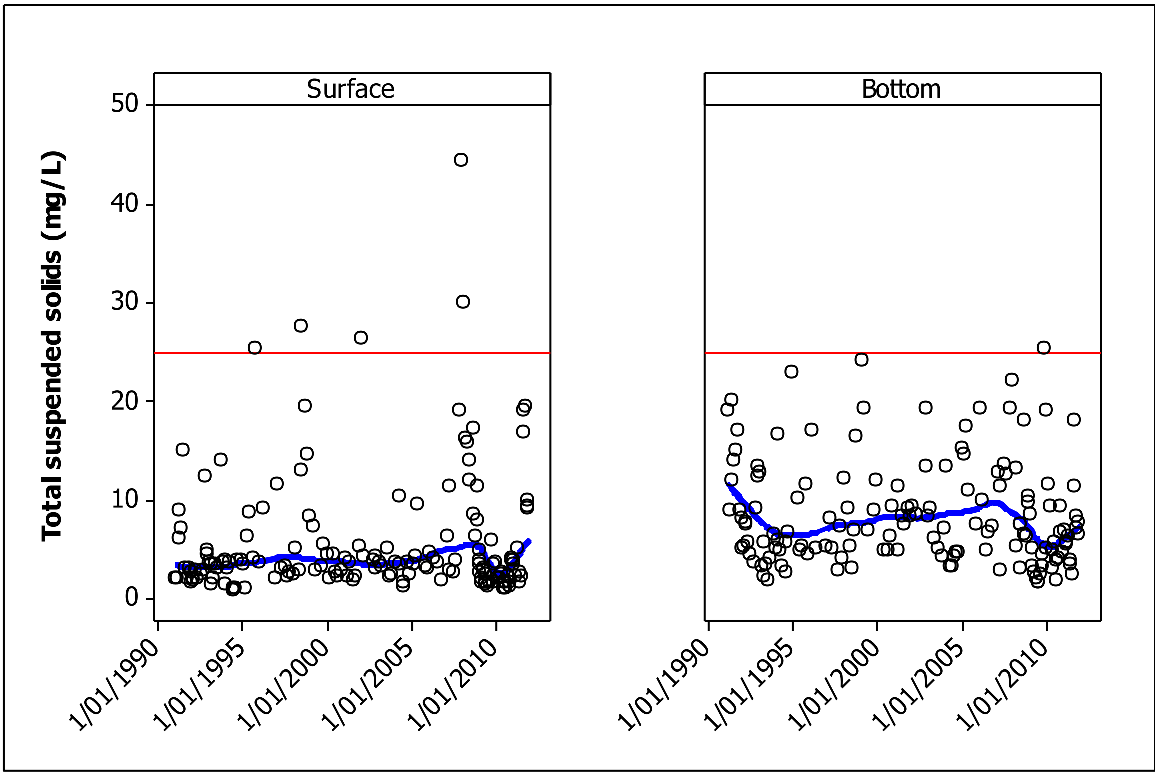

Figure 21: Total suspended solids at the Shaving Point site (SEPP F3 objective shown in the red solid line)

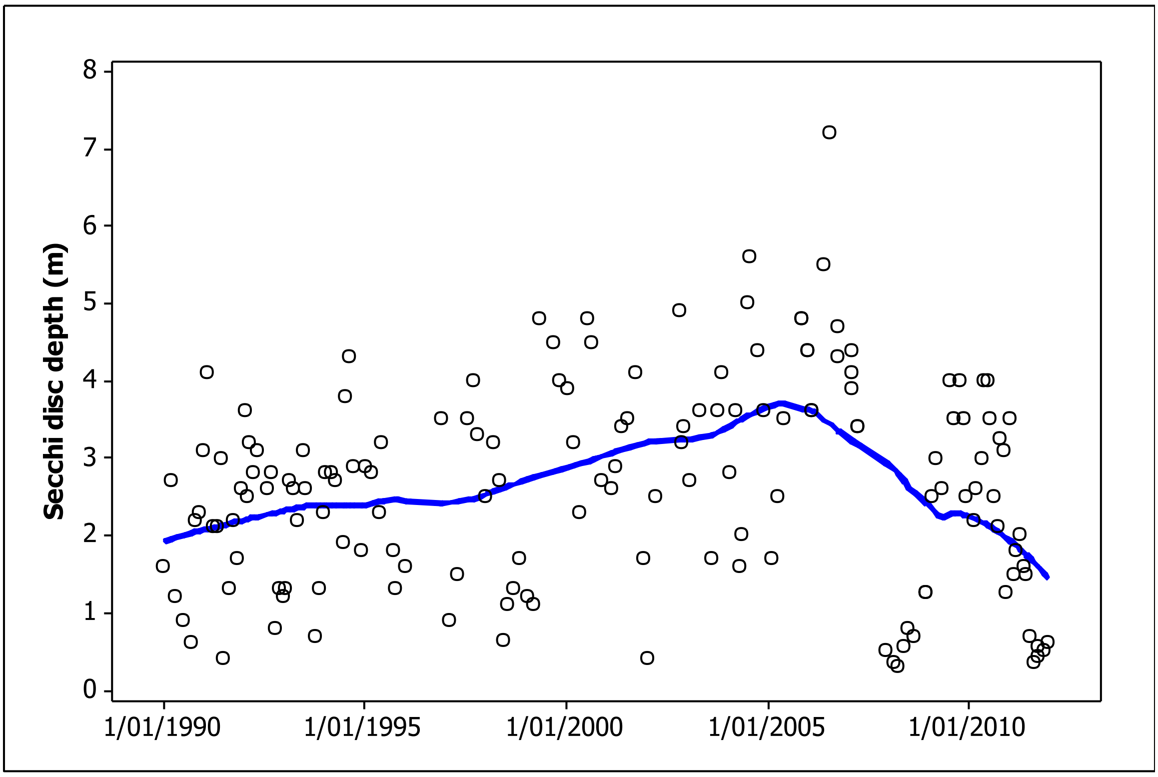

Figure 22: Secchi disc depth at the Lake King South site, for surface waters (no objective exists for Secchi disc depth at this site)

## 5. Baseline shifts in water quality

To analyse the specific impact of climate change on the water quality of the Gippsland Lakes, the fixed sites data set was partitioned into two periods, separated by an observed climatic shift in 1996–97 associated with a shift from a La Niña to an El Niño event (figure 23). This marked the beginning of long term drought conditions in south-eastern Australia. The first period, 'normal period', ranging from 1990 to 1996, is taken as representing climatic conditions for a 'normal' year. The second period, 'drought period', from 1997 to 2010, represents dry years.

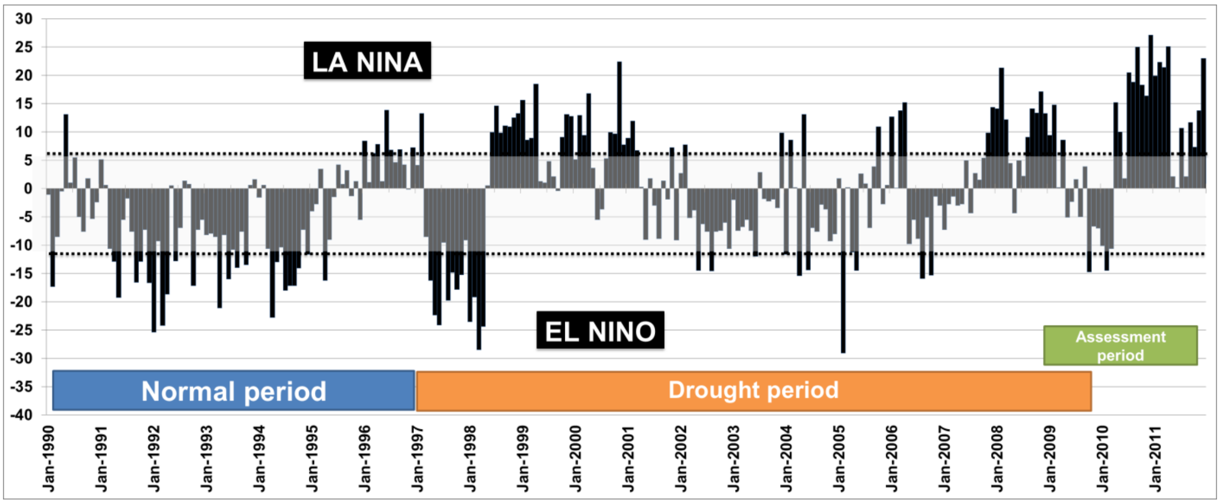

Figure 23: Monthly Southern Oscillation Index against time with super-imposed climatic periods used in a baseline shift assessment. (Dotted lines represent the value above and below which La Niña and El Niño events become significant. Source; Bureau of Meteorology).

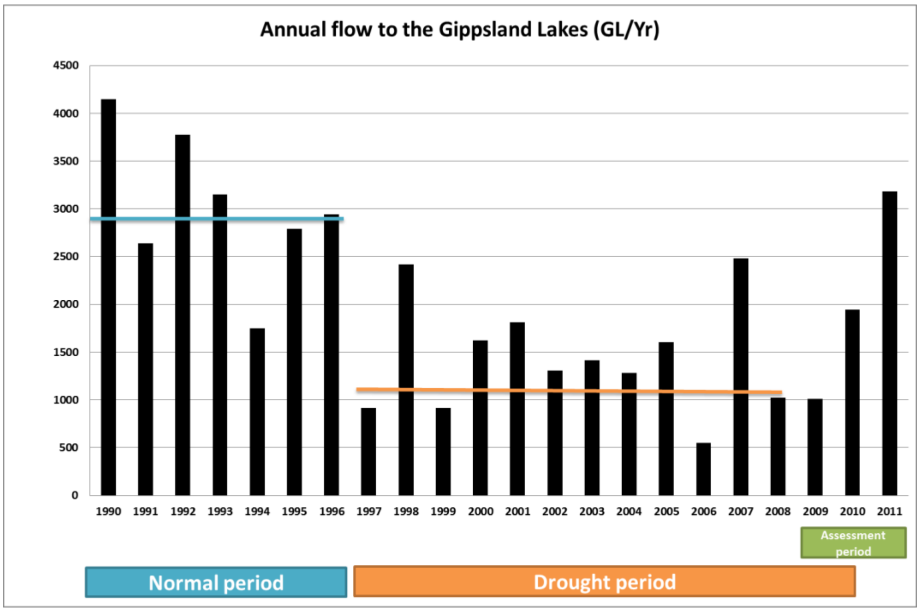

Figure 24: Annual flow to the Gippsland Lakes with super-imposed climatic periods used in a baseline shift assessment. (The average annual inflow for the normal period is plotted in a solid blue line and in solid orange for the drought period).

For the Gippsland Lakes, the climatic shift in 1996-97 translated into a decrease in the average annual flow of about 53 per cent when comparing the drought to the normal period. The average annual flow for the normal period was 3028 GL and 1411 GL during the drought (figure 24). As discussed in the SEPP attainment section of this report, the 2009 to 2011 years represent a gradient from dry to normal catchment inflows.

In addition, the impact of this climatic shift is also visible on rainfall measurements. Figure 25 presents the monthly rainfall anomaly between 1984-1996 ('normal') and 1997-2010 ('drought'), for the Bureau of Meteorology Bairnsdale and Sale stations. A positive anomaly indicates that the climate was drier for the 'drought' period. It is obvious from figure 25 that Sale was experiencing a much drier climate since 1997, with on average, about 12 mm less rain per month (about 150 mm/year). Bairnsdale also had a significant decrease in rainfall (about 110 mm/year), but the variation of rainfall was not consistent over the course of the year. April average rainfall for the 'drought' period appears to be marginally higher than the 'normal' period, while June monthly rainfall appears significantly higher.

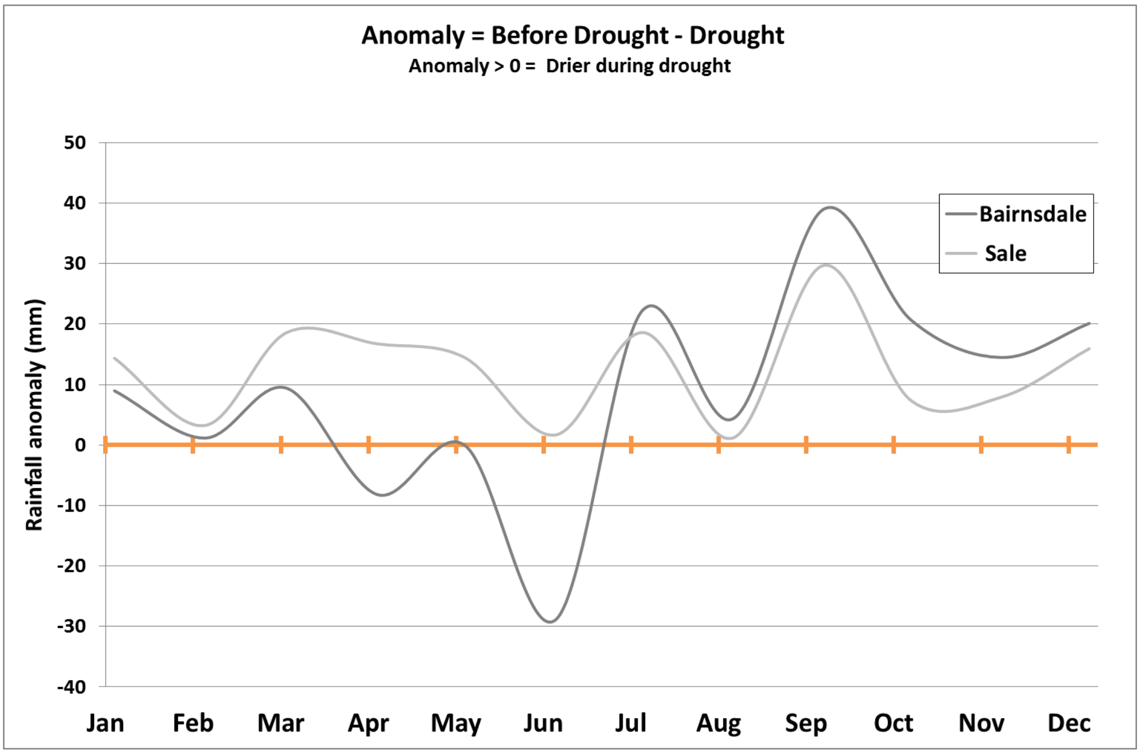

Figure 25: Anomaly in monthly average rainfall at Bairnsdale and Sale between before drought years (1984-96) and during drought (1997-2010)

With regards to temperature, both Sale and Bairnsdale recorded average maximum monthly air temperatures that were higher during the 'dry' period, especially during spring and summer (about one degree Celsius), with the autumn and winter temperatures only being marginally warmer (0.4 degree Celsius, figure 26).

The average monthly minimum temperature appeared to be warmer for summer at both sites, but only the Bairnsdale site appeared to be consistently warmer across the course of the year (albeit very marginally for most of the year, figure 26). Sale average monthly minimum temperatures from March to October were colder during the 'drought' period by about 0.6 degree Celsius (figure 26).

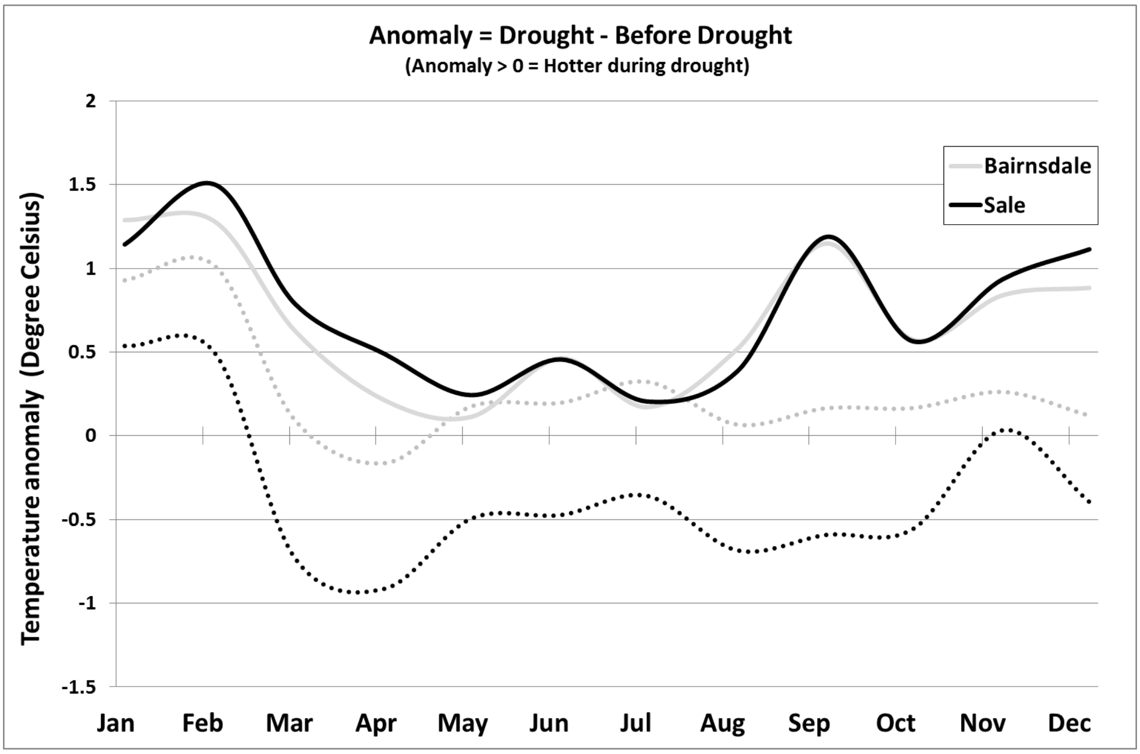

Figure 26: Anomaly in the minimum and maximum monthly average temperature at Bairnsdale and Sale between before drought years (1984-96) and drought (1997-2010); (solid lines indicate maximum average temperature, dashed lines indicate minimum average temperature)

The general decreases in rainfall (and further on river flows) and increases in temperature have had a clear effect on the water quality in the Gippsland Lakes, as seen previously when assessing long term trends and SEPP attainment. This has implications for long term management of the Lakes system and adds difficulty in setting suitable water quality objectives. Traditionally, triggers are set for a period of 10 years but the analysis presented in the previous chapters have shown that depending on climatology, the water quality experienced is widely different. Finding a suitable reference period when the climatic conditions are representative of the typical conditions for the Gippsland Lakes catchment is difficult.

Figures 27 to 35 illustrate this variability further by comparing the distribution (represented by boxplots of the median with 95 per cent confidence intervals) of a range of water quality parameters for the 'dry' and 'normal' periods, and the 2009, 2010 and 2011 years. 2009 was characterised by low inflow to the Gippsland Lakes and considered a dry year, while 2011 was considered normal with a return to average catchment inflows. 2010 was a transitional year during which the drought experienced in Victoria broke. The first part of the year is therefore dry while the rest is relatively wet.

For clarity, when the distribution pattern was similar for the same parameters at different sites, only one site has been presented. For many of the key water quality parameters for the Gippsland Lakes (i.e. salinity, nutrients) the boxplots (figures 27-35) indicate that the years 2009 and 2011 were significantly different. This indicates how the Lakes' function is altered during drought and wet periods and how they regularly shift between two different states.

Salinity variability (figure 27) was smaller and significantly higher during the drought, as opposed to the normal period for surface and bottom waters at all sites. This indicates that the Lakes had shifted to a more saline state, which lasted until 2010 when freshwater inflows returned the Lakes to a more 'normal' state. 2009 was similar to the drought period while 2011 was similar to the normal period. The 2010 year was an 'in between' state where variability was high, reflecting pulses of freshwater (characterised by low values) super-imposed on the drought saline state (represented by high values).

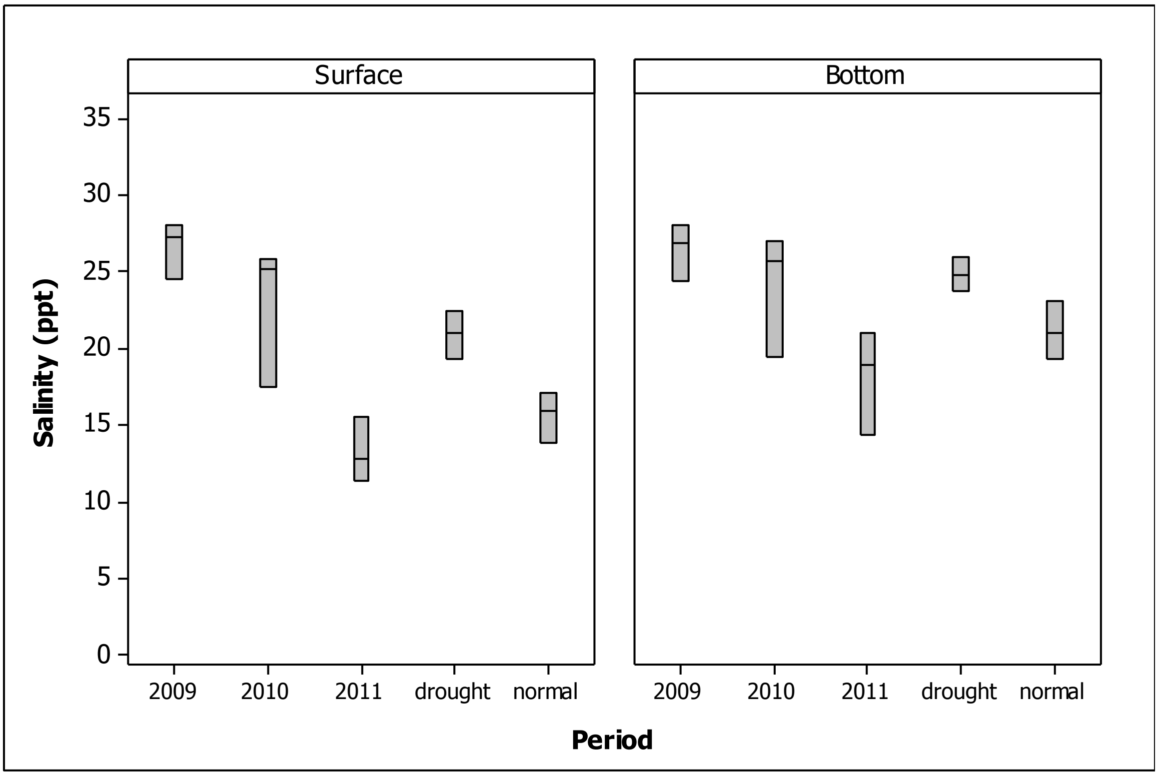

Figure 27: Salinity distribution (median with 95% confidence intervals) at the Lake Victoria site

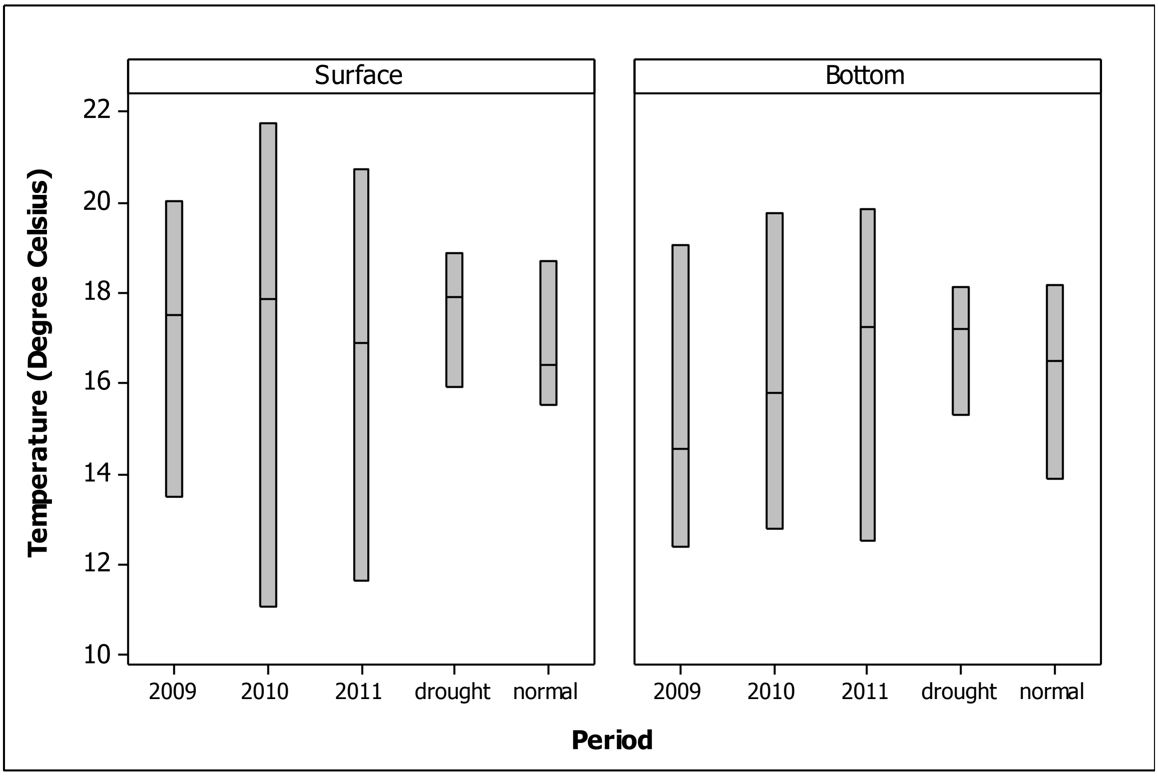

Figure 27: Temperature distribution (median with 95% confidence intervals) at the Lake Wellington site

Temperature medians (figure 28) appeared to have risen slightly at all sites, for the top and bottom waters, between the normal and dry period. Medians for 2009, 2010 and 2011 were widely different from site to site and when compared to the long term medians for the two climatic periods, and no similarities were observable between the sites. This lack of a clear difference is certainly due to the highly seasonal behaviour of temperature masking inter-annual differences.

Dissolved oxygen saturation level distribution (figures 29 and 30) across the dry and normal period have changed significantly for surface waters at the Lake Victoria, Lake King South and Shaving Point sites, with the dry period having lower dissolved oxygen saturation levels. For bottom waters, the dry period distribution appeared to have shifted toward a more oxic state, with the low median's 95 per cent confidence interval shifting up at all sites but Lake Wellington. From 2009 to 2011, the dissolved oxygen saturation decreased while the median confidence interval range extended towards the lower values at all sites. This seems to indicate the development of a more hypoxic condition during wet years. More freshwater inputs increase the risk of stratification developing which will impact on the dissolved oxygen level. Sites prone to stratification had a more drastic shift of dissolved oxygen saturation towards low values, as illustrated in figure 30.

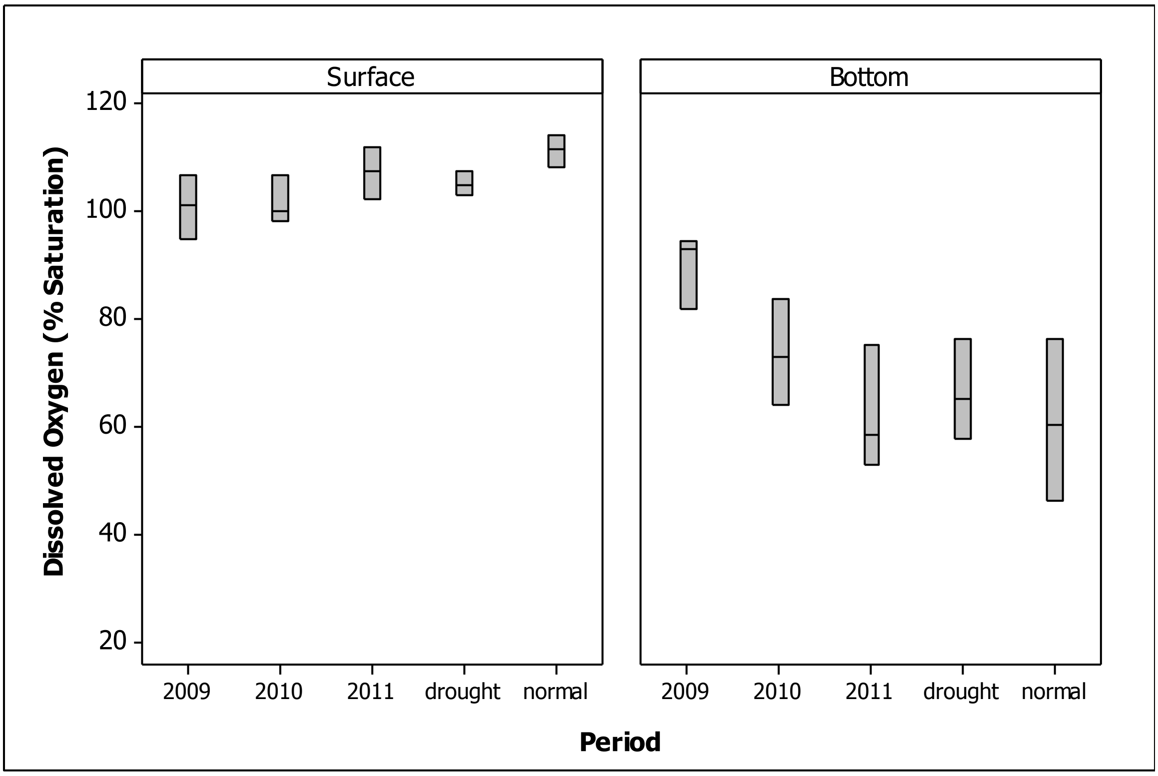

Figure 29: Dissolved oxygen saturation distribution (median with 95% confidence intervals) at the Lake King South site

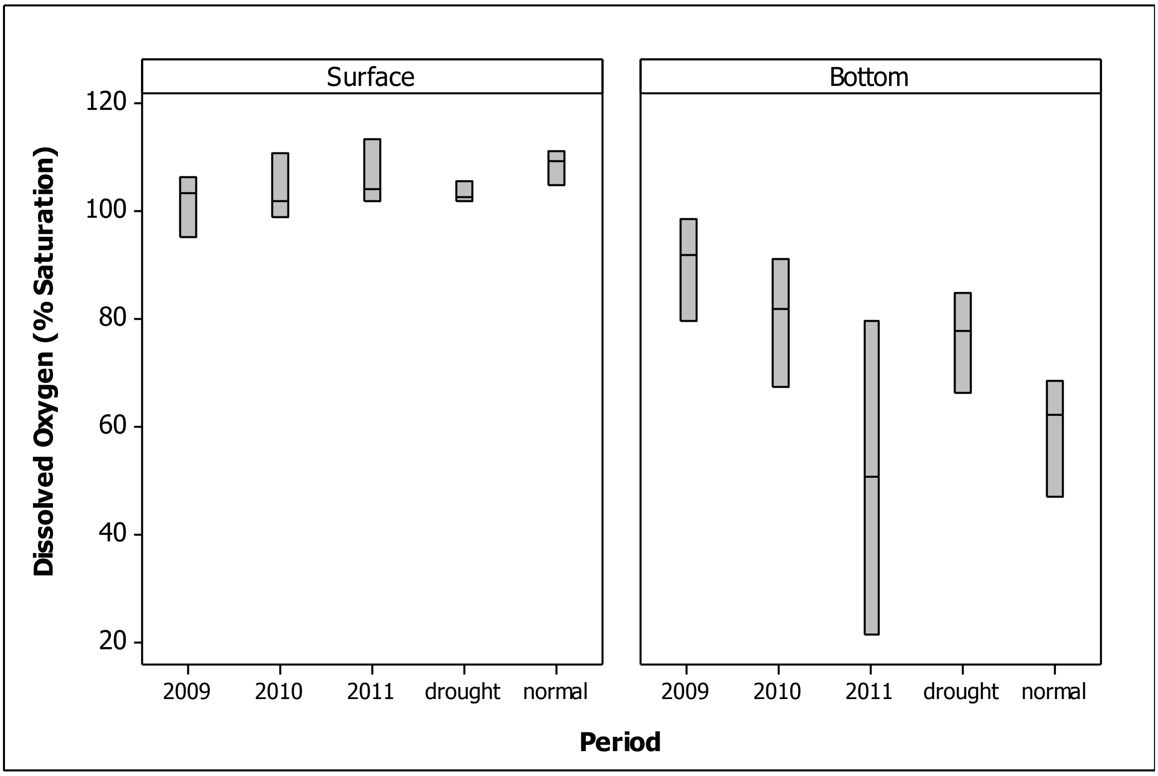

Figure 30: Dissolved oxygen saturation distribution (median with 95% confidence intervals) at the Lake King North site

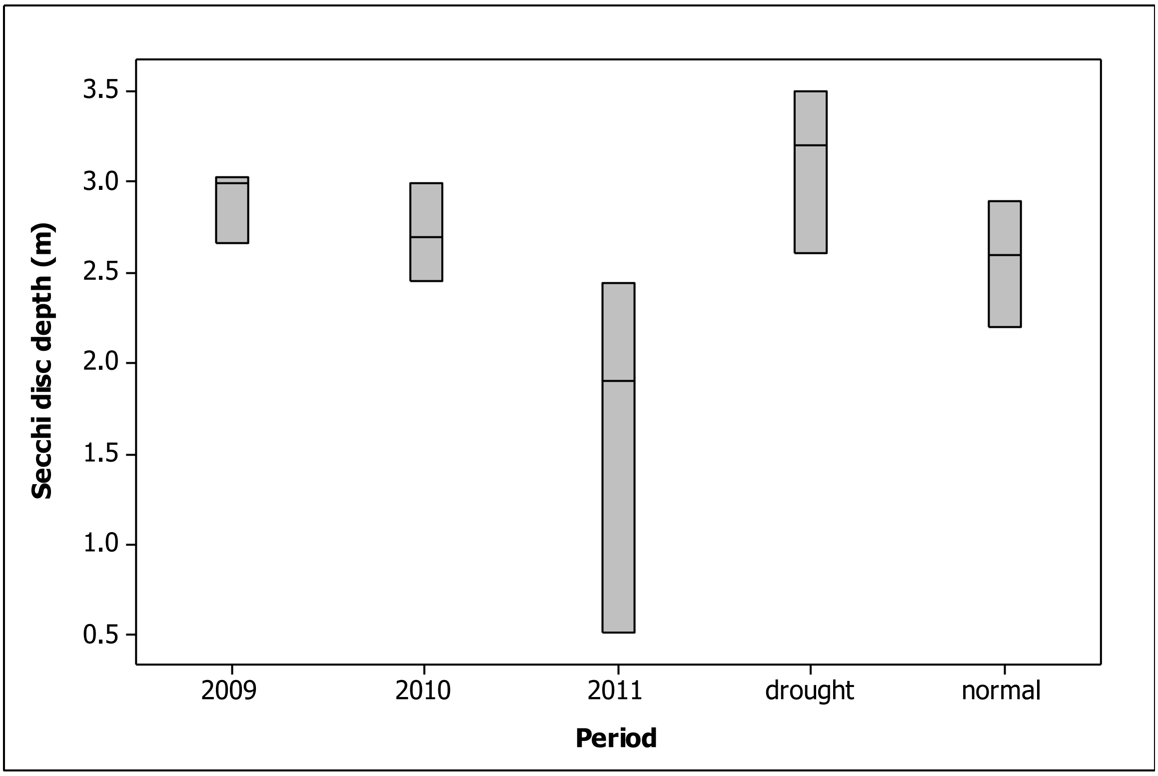

Figure 31: Secchi disc depth distribution (median with 95% confidence intervals) at the Shaving Point site

Secchi disc depth (figure 31) increased (that is, the water got clearer) during the drought period, with the distribution generally shifting toward higher values at all sites. 2009 reflected the drought state while the 2011 showed a normal state. The water clarity decreased with increasing rivers flows as indicated by the increase in the spread of the distribution and the shift in median down for 2011. This catchment influence is observable even at the Shaving Point site, the furthest away from any river input, where the median confidence interval of Secchi disc depth fell to 0.5 m in 2011.

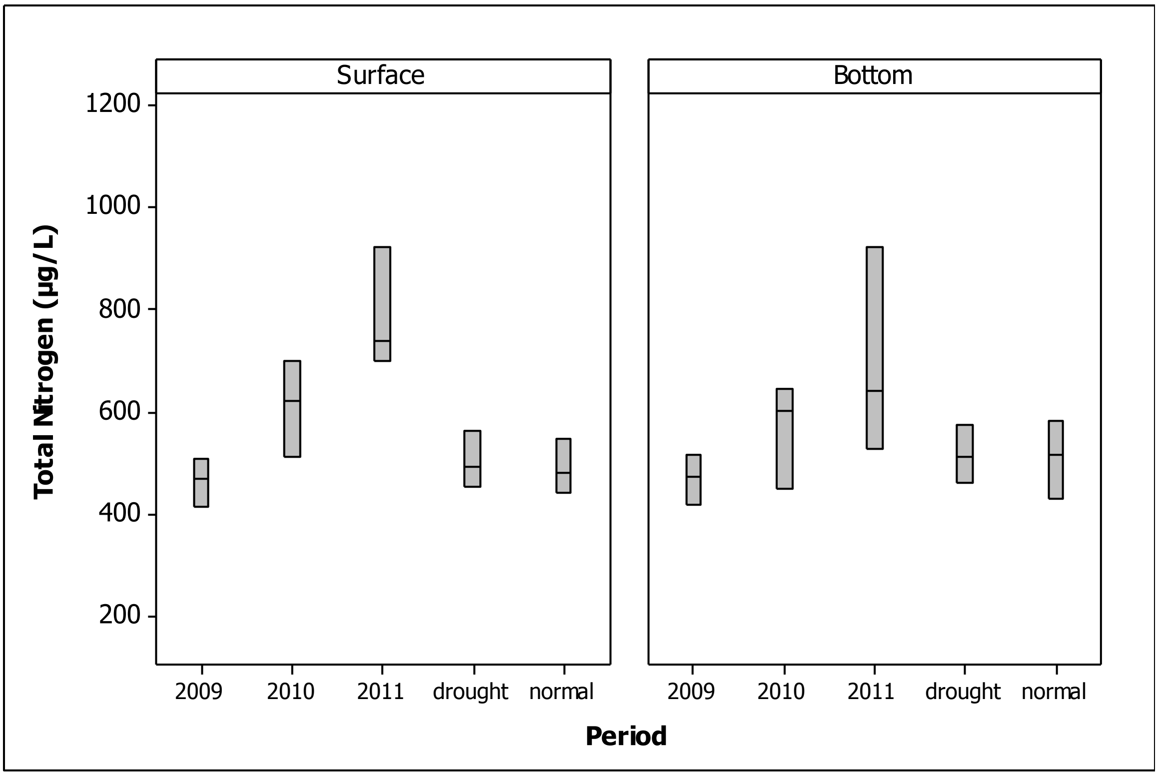

Figure 32: Total nitrogen distribution (median with 95% confidence intervals) at the Lake Victoria site

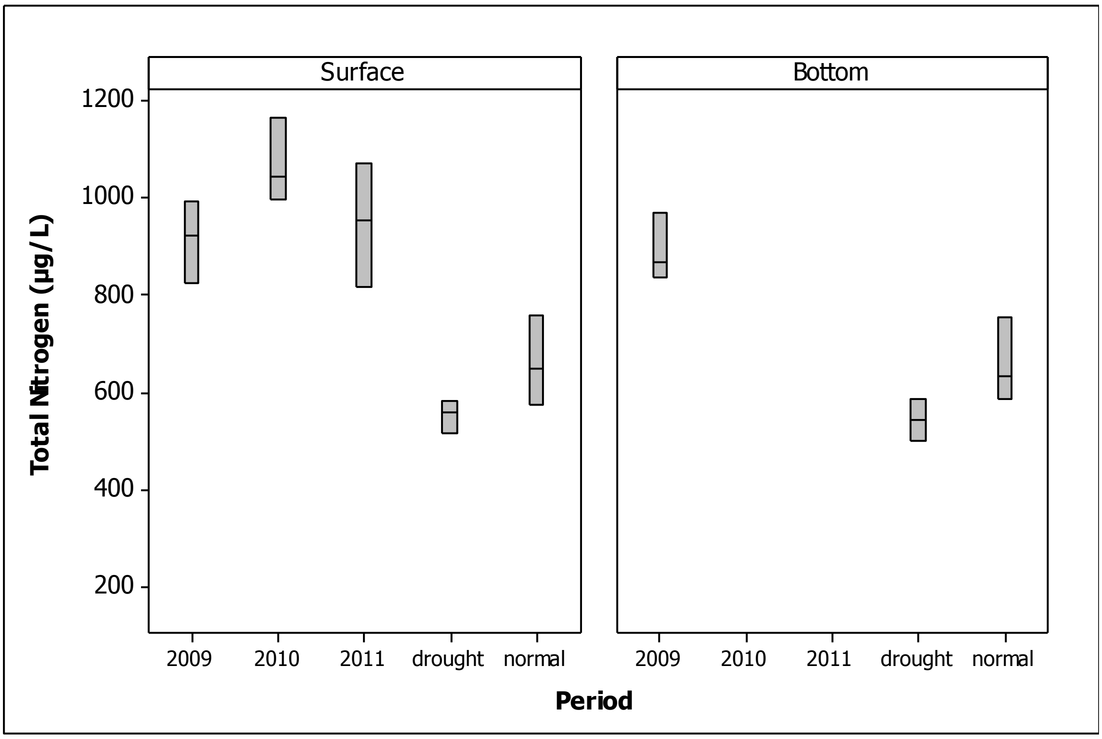

Figure 33: Total nitrogen distribution (median with 95% confidence intervals) at the Lake Wellington site (no data for bottom waters for 2010 and 2011)

Total nitrogen medians were similar at all sites except Lake Wellington, between the dry and normal periods, for both surface and bottom waters. The Lake Wellington total nitrogen median was significantly lower during the dry years for both surface and bottom waters. For 2009 to 2011, total nitrogen medians increased at all sites except Lake Wellington. 2011 also had the largest distribution directly reflecting rivers inputs.

TKN, representing the majority of the nitrogen fraction, total phosphorus, $PO_4$ and NFR followed a similar pattern to total nitrogen and will not be presented here.

$NH_3$ medians (figure 34) for the surface waters did not show any major difference between periods or years. For the bottom waters, no difference between the dry and normal periods existed, but a sharp increase in medians and distribution ranges was present between 2009 and 2011 at all sites but Lake Victoria. Interestingly, Lake King North experienced the highest variability of all sites in 2011, and this was also the case for $PO_4$.

$NO_X$ median confidence intervals followed similar patterns to $NH_3$ and will not be presented.

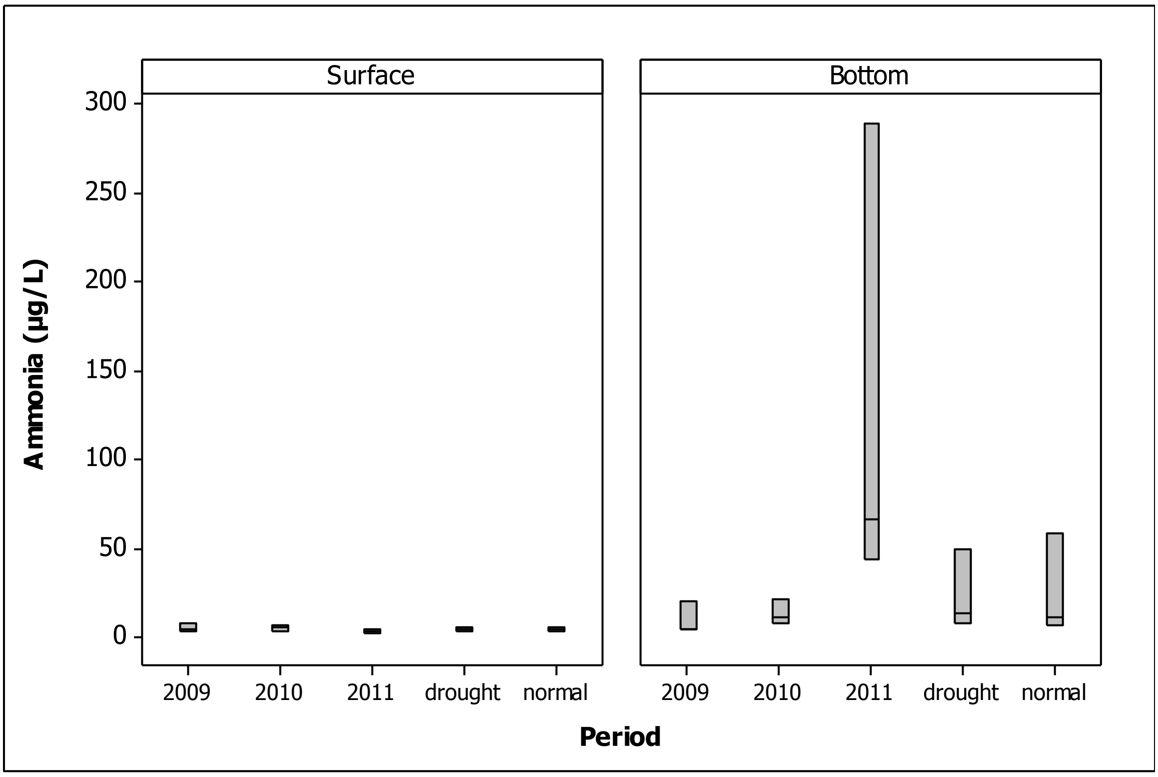

Figure 34: Ammonia distribution (median with 95% confidence intervals) at the Lake King North site

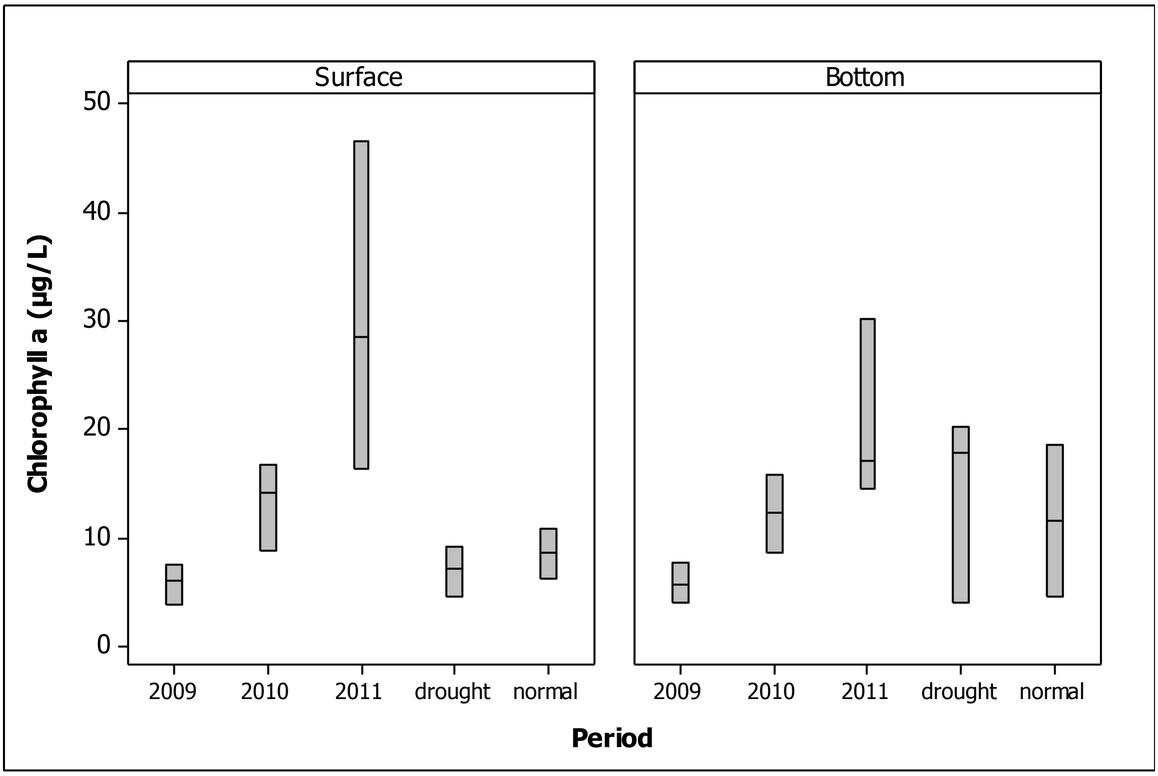

Figure 35: Chlorophyll-*a* distribution (median with 95% confidence intervals) at the Lake Victoria site

Chlorophyll-*a* median confidence intervals (figure 35) showed no significant changes between the two climatic periods for the surface waters, but exhibited a sharp increase between 2009 and 2011 at all sites. The same pattern was also visible in the bottom waters. Chlorophyll-*a* increases are likely to be due to increases in nutrients due to increased inflows. But interestingly, no major difference in the median confidence interval was observed between the dry and normal periods. This reflects the nature of algal blooms, namely sporadic and generally short lived, that can be missed during monthly sampling. This may also reflect the importance of other factors, other than nutrient inputs, in triggering algal growth.

To summarise, during the dry year of 2009, the overall salinity and water temperature of the Lakes system increased. Due to the low rainfall and river flows, the sediments and nutrient loads decreased. As a result, water clarity improved and the nutrient concentrations - in particular total nitrogen - observed at the site most affected by river inputs (Lake Wellington) decreased. As dissolved nutrient levels were low, algal growth was limited and low chlorophyll-a levels were exhibited throughout the Lakes system. Dissolved oxygen levels in surface waters generally decreased in association with the decrease in algal growth, generally enriching surface waters in oxygen. Bottom water oxygenation was higher, certainly reflecting better homogeneity in the water column linked to a decrease in salinity stratification.

In 2010, a transitional period occurred and the dry first months gave way to a wetter spring and summer, resulting in the water quality of the Lakes returning to a more ‘normal’ state during the following year. In 2011, the increased river flows seen since late 2010 impacted on the salinity, which decreased and became more variable throughout the system. Stratification was also largely promoted. With rainfall becoming more persistent and abundant, the sediment and nutrient loads entering the system through catchment inputs increased, negatively impacting on water clarity and increasing nutrient concentrations. In bottom waters, dissolved oxygen saturation decreased under the effect of increased nutrient loads and stratification, promoting nutrient recycling at deep sites. Stimulated by the increase in nutrients, algal growth increased, translating into soaring chlorophyll-*a* levels, and in turn dissolved oxygen levels, particularly in surface waters.

## 6. Discussion and recommendations

The Gippsland Lakes are under enormous pressure from catchment inputs, with nutrient levels and sediments threatening the ecological health of the Lakes by maintaining it at an eutrophic level (OECD, 1982). The water quality in the three lakes is mainly driven by three factors; the proximity to river inputs, the proximity to the entrance and the water depth.

### Characteristics of the Gippsland Lakes

The Lake Wellington site is characterised by eutrophic, turbid and mostly fresh waters. It is a shallow well mixed system without salinity stratification, and mainly a flow-through system with waters originating from its main input, the Latrobe River, rapidly finding its way to the Eastern Lakes through McLennans Strait. As such, its water quality generally reflects the quality of its inputs.

The Eastern Lakes, Lake Victoria and Lake King, have a very different water quality due to the influence of the ocean and their depth. Water quality, measured at the four monitoring sites in these two lakes, exhibits a strong west to east gradient for a wide range of parameters (salinity, particulate nutrients, silicate, suspended solids and chlorophyll-*a*). The concentration of pollutants decreases as salinity increases towards the entrance. The Eastern Lakes are generally salinity stratified and have a long water residence time, and as such, bottom waters can experience periods of low dissolved oxygen. This stimulates the release of dissolved nutrients from the sediments with the deeper sites usually recording the highest concentration of dissolved nutrients. The Shaving Point site, located closest to the ocean entrance and furthest from any river inputs, is an exception. Despite being the deepest, it generally has very low concentrations of dissolved nutrients, with the bottom waters being well oxygenated due to the strong influence of ocean waters at the site.

### Attainment of SEPP water quality objectives

Annual SEPP attainment for the 2009-2011 assessment period, clearly reflects the influences described above, with the Lake Wellington site exceeding more water quality objectives than any other site. Following the west to east gradient in salinity, the number of exceedences decreased from the Lake Victoria site, located immediately downstream of Lake Wellington, to the most eastward Shaving Point site. The Lake King North site had the highest number of exceedences of all sites located in Lake King, for all the years assessed, due to its proximity to freshwater inputs (i.e. the Mitchell, Nicolson and Tambo Rivers).

### Trends over time and the influence of climate

Climatic variation during the assessment period led to a major variation in river inflows to the Gippsland Lakes. The total annual inflow was 1012 GL for the 2009 year, almost doubling to 1942 GL in 2010 and more than tripling to 3182 GL in 2011. Pollutant loading increased with increasing river flow and resulted in an increase in exceedences at all sites from 2009 to 2011. Bottom water exceedences increased the most and were mainly related to a decrease in dissolved oxygen and an increase in dissolved nutrient concentrations. Surface waters exceedences, in contrast, were mostly due to an increase in particulate nutrient concentrations. This clearly reflects the influence of catchment inputs, with a significant increase in the input of fresh water rich in particulate nutrients, increasing salinity stratification in the Eastern Lakes. This in turn triggers a decrease in oxygen in the bottom waters and a release of dissolved nutrients from the sediments.

The release of dissolved nutrients from the sediments is a very important process for the Gippsland Lakes as the amount of nutrients stored in the sediment is extremely large. Webster and Wallace (2000) calculated that the time to deplete the sediment store of nutrients, without any resupply, varied between a decade to a century. Longmore and Roberts (2006) estimated that the dissolved nutrients released from the sediments were equivalent to between one and a half and four years of catchment supply and large enough to supply a large algal bloom in as little as 10 days. They also identified large geographical variability, larger than seasonal variability. Further monitoring and assessment is needed to fully quantify the potential impact of sediment-bound nutrients and assess whether any remediation is warranted.

This catchment influence on water quality is also clearly visible in the long term trends and baseline shift analysis. During the dry years between 1997 and 2009, water quality of the Gippsland Lakes was better than during the normal (1990-1996) period. Chlorophyll-*a*, particulate nutrients and suspended sediments concentrations decreased from the normal to the drought period and increased when the drought broke in 2009. Salinity, dissolved oxygen saturation and Secchi disc depth follow the opposite pattern in that they increased during the dry years and decreased when flows increased.

### Current limitations and options for the future

The climatic influence observed on the water quality in the Gippsland Lakes is significant. Interpreting the influence is critical for policy makers and natural resource managers. For managers, climatic effects can mask the effectiveness of the implementation of best management practices. From a policy perspective, it is crucial to find a suitable reference period when deriving water quality objectives. Accounting for climatic variation renders this a difficult but necessary task.

During the SEPP attainment analysis of the water quality data collected within the fixed site program, a range of shortcomings was identified and these limited the power of the analysis presented in this report. The shortcomings were mainly related to the limited number of indicators defined in the SEPP policy, the lack of specific objectives for surface and bottom waters and the inadequacy of the existing objectives due to the reference period on which they were based.

The existing objectives were derived from three years of monitoring in the late 1970s and included the biggest flood on record the Gippsland Lakes have experienced, in 1978. As a result, some water quality objectives were set too high and were not exceeded, even during the wet 2011 year. In addition, there are no specific limits specified for some of the key threats to the water quality of the Gippsland Lakes. For example, there are no specific nutrient limits despite being one of the biggest contributors to bad water quality. There are also no specific limits for surface and bottom waters. This could be acceptable for the well mixed Lake Wellington but not for the stratification prone Eastern Lakes. Finally, catchment land use and urbanisation have drastically changed since the policy objectives were developed and need to be updated to ensure the ongoing protection of the beneficial uses identified in the Gippsland Lakes.

As previously mentioned, the ecological health of the Gippsland Lakes is driven by the quality and quantity of catchment inputs, sediments behaviour (i.e. storage and release of nutrients) and oceanic influence. The Lakes would vastly benefit from a more and better integrated monitoring and reporting program, encompassing sediment and catchment impacts, helping improve the effectiveness of management actions undertaken to protect the Lakes.

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## Appendix A: Water quality policy

State Environment Protection Policy, Waters of Victoria

SEPP, Waters of Victoria (schedule F3) was established in 1988 as a comprehensive policy framework for the protection of water quality in the Gippsland Lakes. Subsequently, Waters of Victoria (schedule F5) was produced to further protect the Gippsland Lakes. Protecting beneficial uses is the basis for maintaining environmental quality.

In the Lakes these beneficial uses consist of:

- The maintenance of natural aquatic ecosystems
- Water based recreation
- The production of molluscs for human consumption
- Commercial and recreational use of edible fish and crustacea.

Within the Lakes two segments or regions are recognised that reflect the different types and conditions of the environment:

- *Lake Wellington segment*: includes the surface waters of Lake Wellington and McLennans Strait
- *Eastern Lakes segment:* includes the surface waters of Lake Victoria, Lake King, Cunningham Arm, North Arm, Lake Bunga and Victoria Lagoon.

Environmental quality objectives have been set in each segment to ensure the protection of designated beneficial uses and are provided in table 7. The objectives provide targets for particular indicators that are a measure of the condition of the Lakes' environments. For the Gippsland Lakes, nutrients and chlorophyll-*a* concentrations have not been specified in the objectives. The parameters specified are dissolved oxygen, pH, temperature variation, turbidity and suspended solids. As nutrient objectives are not set in SEPP, Waters of Victoria, the ANZECC National Water Quality Management Strategy Guidelines (2000) values are used. In Waters of Victoria, schedule F5, a further environmental objective was set. This is that by 2005 the total phosphorus load in Lake Wellington must be less than 115 tonnes/year for a median annual stream flow, and must be at a level to ensure the annual median concentration of chlorophyll-*a* in Lake Wellington shall be no greater than 8 ↔g/L. This level of chlorophyll-*a* was chosen as it would mean that Lake Wellington would be classified as mesotrophic.

## Table 7: SEPP schedules F3 and F5, and ANZECC water quality objectives applicable to the Gippsland Lakes

| Indicator | Unit | Parameter | Source | Lake Wellington | Eastern Lakes |
|---|---|---|---|---|---|
| Dissolved oxygen | mg/L | Minimum | SEPP F3 | >6 | >6 |
| | % saturation | | | >60 | >75 |
| pH | pH units | Range | SEPP F3 | 6-9 | 6.5-8.5 |
| | | Variation | | 1 | 0.5 |
| Temperature | Degree Celsius | Variation | SEPP F3 | ±2 | ±1 |
| Toxicants [1] | µg/L | Maximum | ANZECC | ANZECC | ANZECC |
| Total dissolved solids | mg/L | Annual median | SEPP F3 | 8000 | - [2] |
| Turbidity | NTU | Annual median | SEPP F3 | 15 | - |
| | | 90th percentile | | 80 | - |
| Suspended solids | mg/L | Annual median | SEPP F3 | 25 | 25 |
| | | 90th percentile | | 80 | 80 |
| Chlorophyll-*a* | µg/L | Annual median | SEPP F5 | 8 | |
| | | January-June median | | 5 | |
| Total phosphorus [1] | µg/L | Annual median | ANZECC | <30 | <30 |
| Dissolved inorganic phosphorus [1] | µg/L | Annual median | ANZECC | <5 | <5 |
| Total nitrogen [1] | µg/L | Annual median | ANZECC | <300 | <300 |
| Oxides of nitrogen [1] | µg/L | Annual median | ANZECC | <15 | <15 |
| Ammonium [1] | µg/L | Annual median | ANZECC | <15 | <15 |

[1] ANZECC (2000) guideline trigger values supersede schedule F3 since WoV, 2003

[2] Management agencies in conjunction with local communities shall assess appropriate salinity objectives for the Eastern Lakes segment

## Appendix B: Description of water quality parameters

### Nutrients and chlorophyll

Nutrient enrichment (eutrophication) or changes in the balance of nutrient concentrations pose serious risks to the environmental quality of marine systems. The consequences of eutrophication could result in undesirable changes to ecological processes. This may lead to the loss of productive aquatic ecosystems and the establishment of noxious algal problems (EPA 1997).

Information on the ambient concentrations of inorganic nitrogen and phosphorus species, organic and total phosphorus and indicators derived from these is an essential part of understanding the trophic status of aquatic systems (Newell and Harris 1997).

More specifically:

Nitrogen: This is the key nutrient determining the rate of primary production in marine ecosystems. Dissolved inorganic nitrogen (DIN) in the form of nitrate ($NO_3$), nitrite ($NO_2$) and ammonia ($NH_3$) are readily used by phytoplankton in photosynthesis. The dominance of the major inorganic nitrogen species varies among sources and can vary seasonally. Nitrogen is also removed from the Lakes as gaseous nitrogen ($N_2$) by denitrification.

Phosphorus: Phosphorus is required by phytoplankton for growth and may, under some circumstances, limit the rate of primary production. Orthophosphate ($PO_4$) is the form most readily available to phytoplankton. The phosphorus data presented in this report is for dissolved inorganic phosphorus and this is mostly composed of orthophosphate.

Silicate: The availability of silicate in a water body has little or no influence on the overall rate of primary production but influences the composition of phytoplankton. When silicate is abundant, diatoms are one of the major components of the phytoplankton. When silicate is in low supply, other classes of algae dominate the phytoplankton composition. Inputs of biologically available silicate come largely from the weathering of soils and sediments, and are transported by rivers to the Lakes.

Chlorophylls: Chlorophylls are photosynthetic pigments found in plants. Chlorophyll-*a* is common to all plants. Its concentration is used as an approximate measure of the biomass of photosynthetic plants and an index of the productivity of a water body. It is often used as an integrated surrogate measure of nutrient status. Chlorophyll-b, chlorophyll-c and carotenoids are other pigments utilised by different types of plants to absorb light under varying light conditions. Phaeopigments are chlorophyll degradation products resulting, for example, from grazing of phytoplankton by zooplankton.

### Physicochemical indicators

Salinity is a measure of the amount of dissolved solids in water. It is reported in accordance with the Practical Salinity Scale of 1978, where practical salinity unit (PSU) values are equivalent to parts per thousand. As a general rule, ocean water has a salinity of about 35.5 PSU, while freshwater has a salinity of less than 2 PSU. Values in between these two extremes indicate mixing of seawater with varying proportions of freshwater.

Salinity can also be affected by evaporation. Water temperature generally varies with the season, reflecting background climatic conditions. Temperature and salinity values are required for the calculation of the saturation level of dissolved oxygen. Dissolved oxygen is essential for sustaining the life cycle of most aquatic organisms. Its concentration in the water column results from the balance between consumption (respiration), production (photosynthesis) and diffusion from the overlying atmosphere. A water column in equilibrium with the atmosphere is at 100 per cent saturation.

The concentration of dissolved oxygen represents one aspect of the health of a system. High dissolved oxygen concentrations allow for healthy plant and animal growth, while low dissolved oxygen concentrations indicate that fauna may be under stress.

### Suspended solids and water clarity

Non-filterable residue (NFR) or total suspended solids (TSS) are an indicator of particulate matter inputs and/or re-suspended sediments. This is captured when water is filtered through a glass fibre filter. The pore size of the filter is approximately 0.7 $\mu$m. NFR decreases water clarity and impacts on plant photosynthesis and amenity of the water body.

Secchi disc depth is a visual measure of the ability of light to penetrate water. This is a traditional measure of water clarity, and is done by lowering down the water column a 30 cm disc that is divided into alternating black and white segments, until it is no longer visible. Low Secchi disc depth indicates low water clarity, which may be caused by suspended sediments or plankton blooms. Secchi disc depth depends on the perception of the person making the measurement and this is affected by the prevailing light and water surface conditions.

### Toxicants

High concentrations of toxicants such as metals and organic compounds in waters pose a threat to the health of aquatic ecosystems. They also threaten environmental uses and values (beneficial uses), such as the production and consumption of commercial seafood. Monitoring of toxicants in the water column can provide an early warning of changes that could impact on marine organisms and beneficial uses.

## Appendix C: Sampling methodology and quality control

### Methods

**Field sampling**

EPA personnel or contractors who are trained in the sampling methodology, conduct all field sampling. Fieldwork involves both in-situ monitoring and the collection of water samples for laboratory analysis. Field sampling is undertaken monthly around the third full week of the month.

**In-situ monitoring**

A Hach DS-5X Hydrolab is used to measure the in-situ parameters at each site, including salinity, depth, temperature, dissolved oxygen (% saturation), photosynthetic active radiation (PAR), fluorescence and turbidity. A Secchi disc and measured line is used to measure Secchi disc depth.

**Water quality**

Water samples are collected using a Niskin bottle and measured line. Samples are collected at the near surface (~0.5 m) of the water column and at depth (~0.5 m from the bottom). Sub-samples are withdrawn for salinity, dissolved oxygen, nutrients, chlorophyll-*a* and suspended solids. Sub-samples are filtered through 0.45 μm membrane filters and stored for dissolved nutrient analysis. Chlorophyll-*a* samples are collected by gravity filtration of seawater through a glass fibre filter and stored on ice. Suspended solids samples are collected by gravity filtration of seawater through a pre-weighted filter paper and stored on ice.

**Sample blanks and replicates**

Field sampling quality control measures include the collection of a field blank and a replicate. This includes:

- one freshwater field blank per cruise to test for contamination during sample collection/treatment/storage
- one field replicate to test for contamination during sample collection/treatment/storage, site heterogeneity and laboratory precision. One site is randomly selected during each monthly sampling cycle, and the replicate sample is analysed for each of the parameters normally tested. The replicate sample site remains blind as far as the laboratories are concerned. Where a replicate is taken, a filtered replicate is also collected for required parameters.

**Quality assurance for field sampling**

Quality assurance for fieldwork includes:

- sampling for nutrients carried out using powder-free, nitrile disposable gloves to minimise contamination
- sampling equipment left open to the water column for approximately two minutes allowing it to sufficiently rinse prior to taking a sample
- all samples stored on ice and transported to the laboratories within 48 hours of collection
- collection of field blanks and replicates
- chain of custody forms created and forwarded with the samples to the laboratories.

### Laboratory analysis

The laboratory analysis of samples is contracted to Department of Primary Industries (DPI) Queenscliff for nutrients, salinity, dissolved oxygen, chlorophyll-*a* and suspended solids.

Reports are provided by the laboratories detailing their QAQC programs, while EPA also undertakes internal QAQC to ensure quality control for laboratory results.

### Underway monitoring (results from this are not presented in this report)

Using a water pick-up tube suspended below a moving boat, surface water goes through a BBE Moldaenke FluoroProbe measuring algal pigment concentration for diatoms/dinoflagellates, green algae, blue-green algae and cryptophytes, as well as total algal biomass. The water is then directed through a SeaBird Electronics SBE45 Salinometer, recording conductivity (salinity) and temperature. Finally, a WetLabs FLNTU measures turbidity and chlorophyll-*a* fluorescence. By utilising a handheld GPS, these water quality parameters are measured, recorded and displayed in real time every three seconds at boat speeds in excess of 30 knots. This allows spatial coverage across the Lakes system. Generalised spatially interpolated contour plots of chlorophyll-*a* and other parameters (e.g. salinity) are created in ArcGIS using spline as the interpolation method. As the contour boundaries are software derived, the final result is dependent on the interpolation method, settings and data density. However, they provide a useful indication of spatial variability.

### Data reliability

The determination of trends is complicated by problems associated with the characteristics of the environmental data. For example, any small change in analytical methodology or sampling procedures throughout the study can cause a shift in the mean or in the variance of the measured values (Gilbert 1987). These shifts could be incorrectly interpreted.

When looking at time series plots of temporal monitoring data, the most noticeable visual features of the data are sometimes the results of the relatively frequent ad hoc changes to aspects of the monitoring program.

Abrupt variations in the mean and variance of some of the indicators suggest that there may have been changes in analytical methods, and laboratory and sampling procedures. It is established that some physicochemical indicators, such as salinity and dissolved oxygen, which were originally analysed in situ, were later analysed in the laboratory because it was suspected that field measurements were not providing reliable data. However, other procedural changes were not adequately documented. Therefore, following discussions with analysts at the Marine and Freshwater Resources Institute (MAFRI), Department of Primary Industries, it was decided to only analyse data from 1990 to present. Procedural improvements in the analytical chemistry and sampling techniques introduced during the mid to late 1980s, such as the introduction of clean laboratory procedures, provide greater confidence in the data obtained since that time.

## Appendix D: Spatial and temporal gradients

Figures 41 to 56 illustrate the east-west gradient for salinity, total nitrogen (TN), silicate (Si), total Kjeldahl nitrogen (TKN, a proxy of the amount of organic nitrogen present in the water column), non-filterable residue (NFR, a proxy for the amount of sediment suspended in the water column) and total phosphorus (TP).

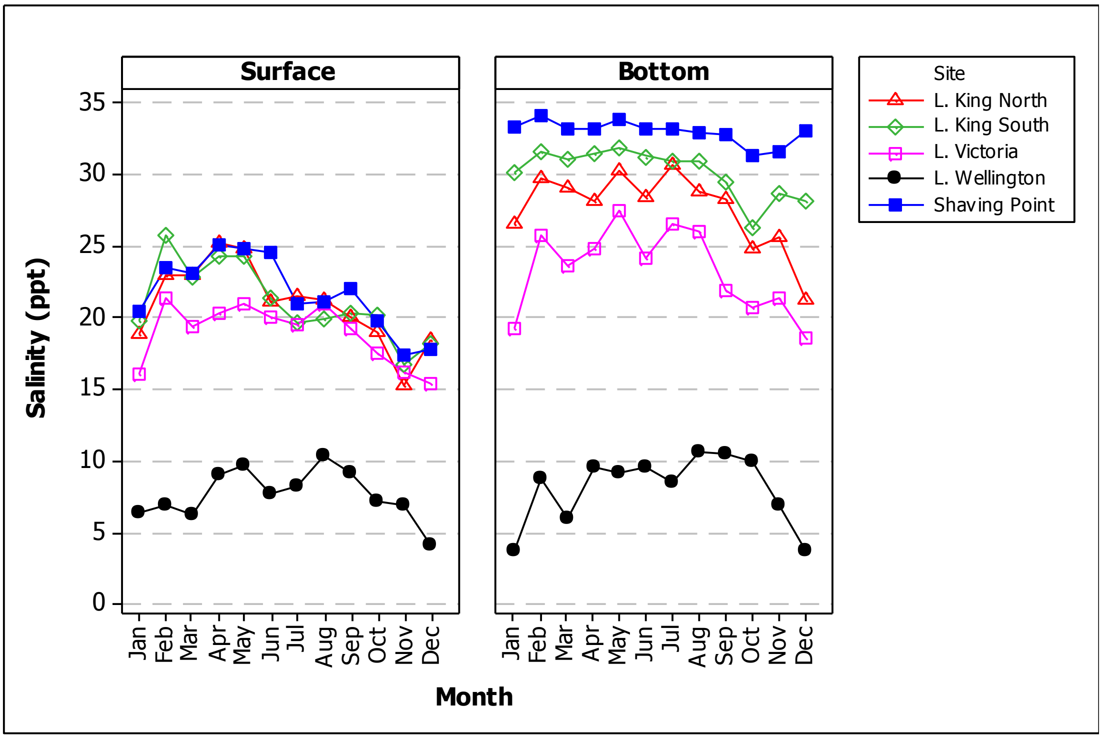

Figure 41: Monthly median of salinity

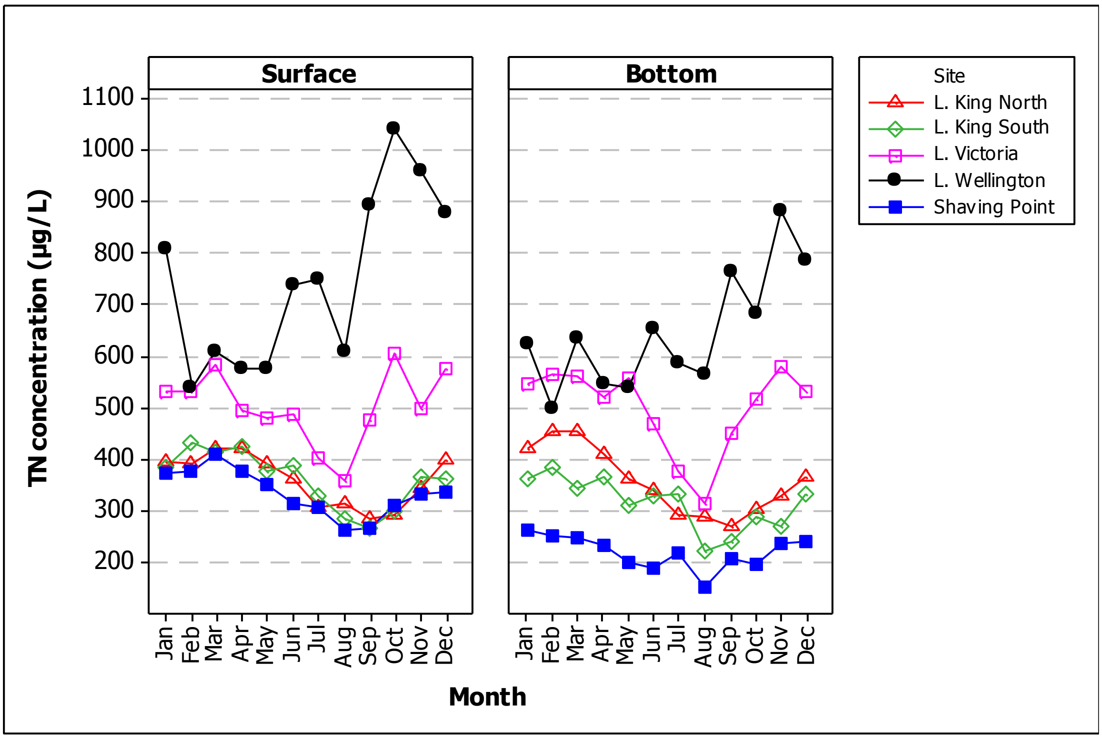

Figure 42: Monthly median of total nitrogen

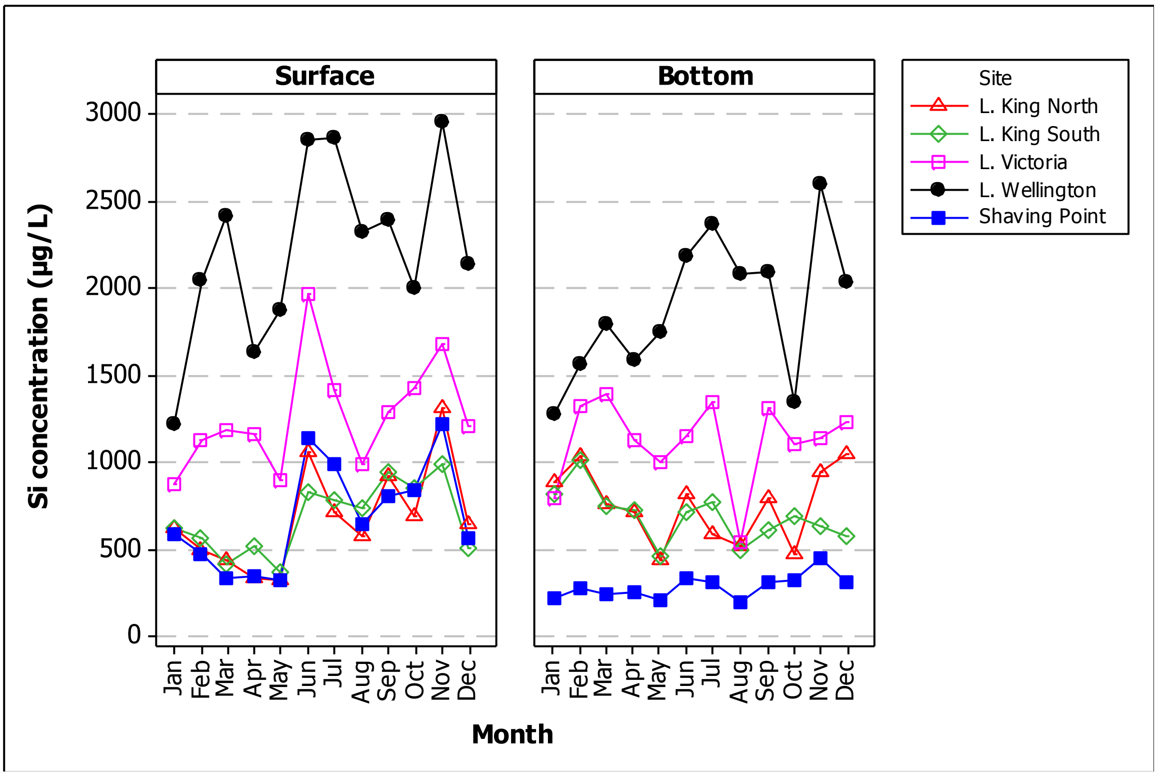

Figure 43: Monthly median of silicate

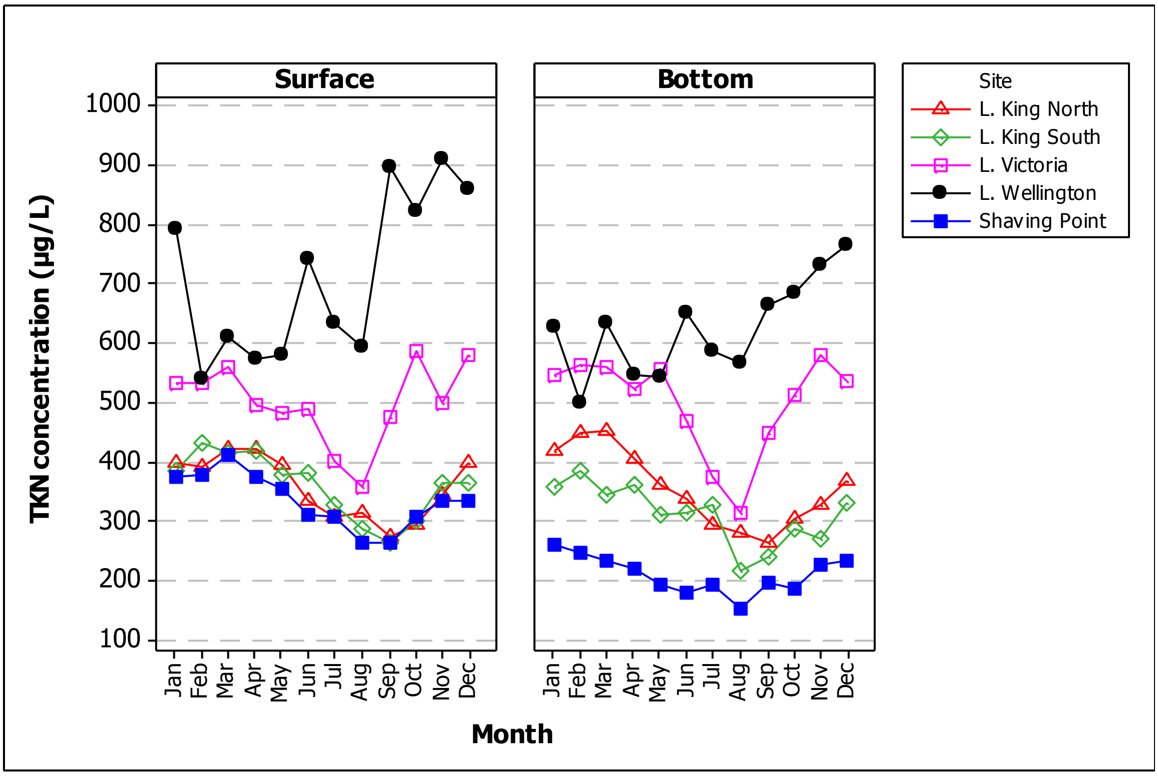

Figure 44: Monthly median of total Kjeldahl nitrogen

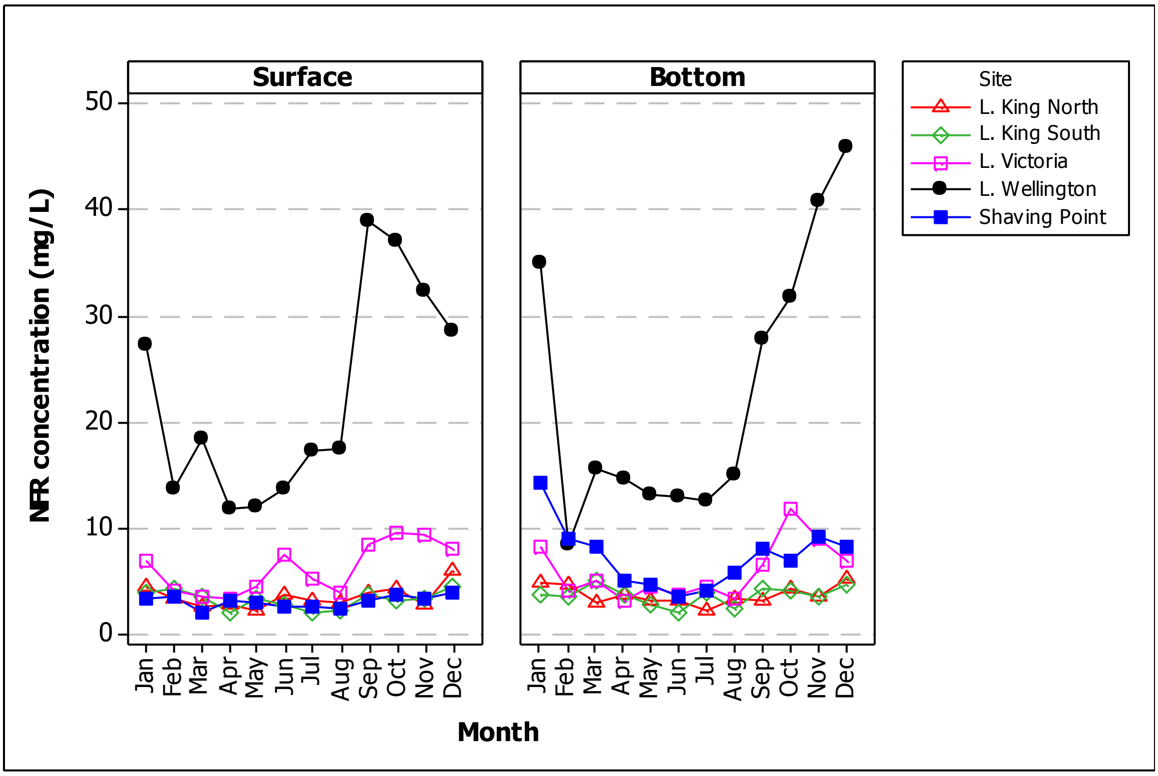

Figure 45: Monthly median of non-filterable residues

Salinity increased drastically from the Lake Wellington site to the Lake Victoria site and less markedly toward the more saline, ocean influenced Shaving Point site. The strong difference between Lake Wellington and Lake Victoria is due to the McLennans Strait acting as a barrier to salt water intrusion into Lake Wellington. This limited exchange of salt water from Lake Victoria to Lake Wellington also explains the strong differences that exist in the salinity range experienced at the top and the bottom of the water column at the different monitoring sites. The Lake Wellington site had a much lower range of variability between its surface and bottom waters as opposed to the other sites. This is certainly due to its morphological features (broad, flat bottom and shallow) facilitating wind mixing. Interestingly, the two Lake King sites had similar salinities both at the surface and the bottom of the water column, and were much closer related than any other sites despite the distance separating them.

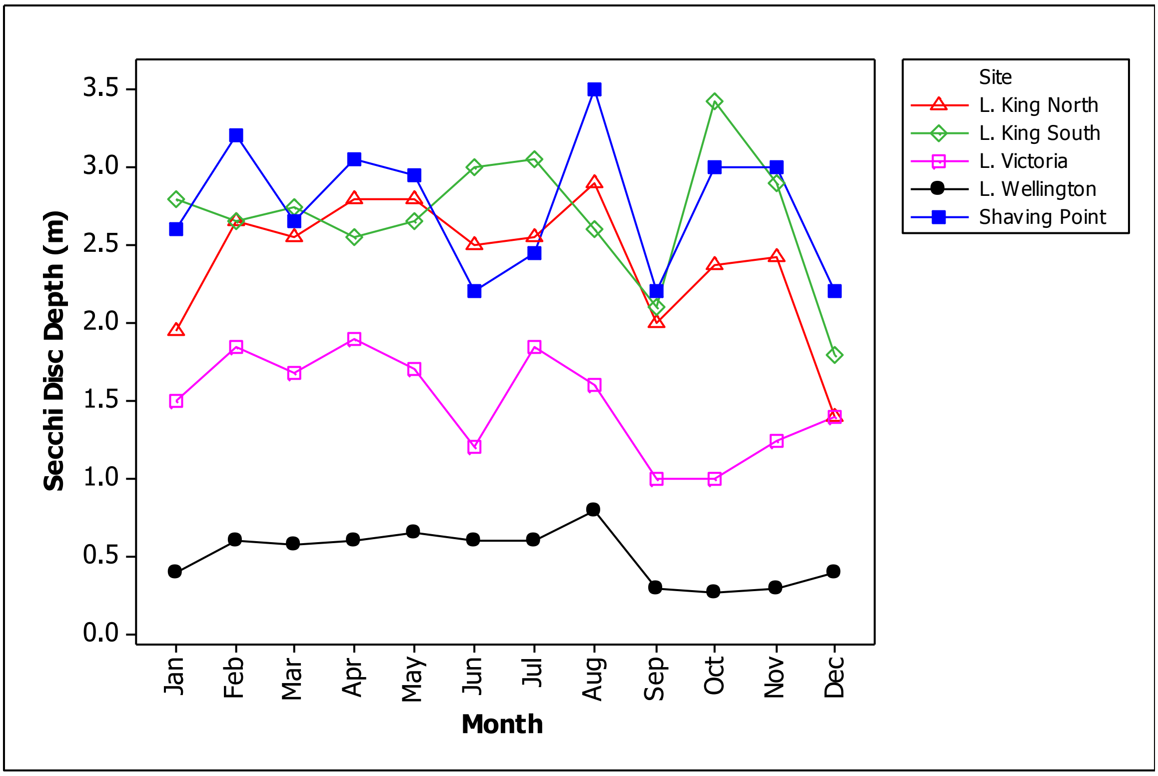

Figure 46: Monthly median of Secchi disc depth

As explained earlier, the major inputs of nutrients and sediments to the Gippsland Lakes come from the rivers, thus sites located close to river mouths experience the highest concentrations. The TN, TKN, Si and NFR graphics reflected this clearly (figures 42 to 45). Lake Wellington consistently recorded the highest nutrient concentrations and the Shaving Point site in Lake King typically had the lowest concentrations. Secchi disc depth (figure 46), which indicates water clarity, also showed a similar pattern but inverted. This is because the higher the Secchi disc depth, the clearer the water is. Again, the two Lake King sites appeared very similar.

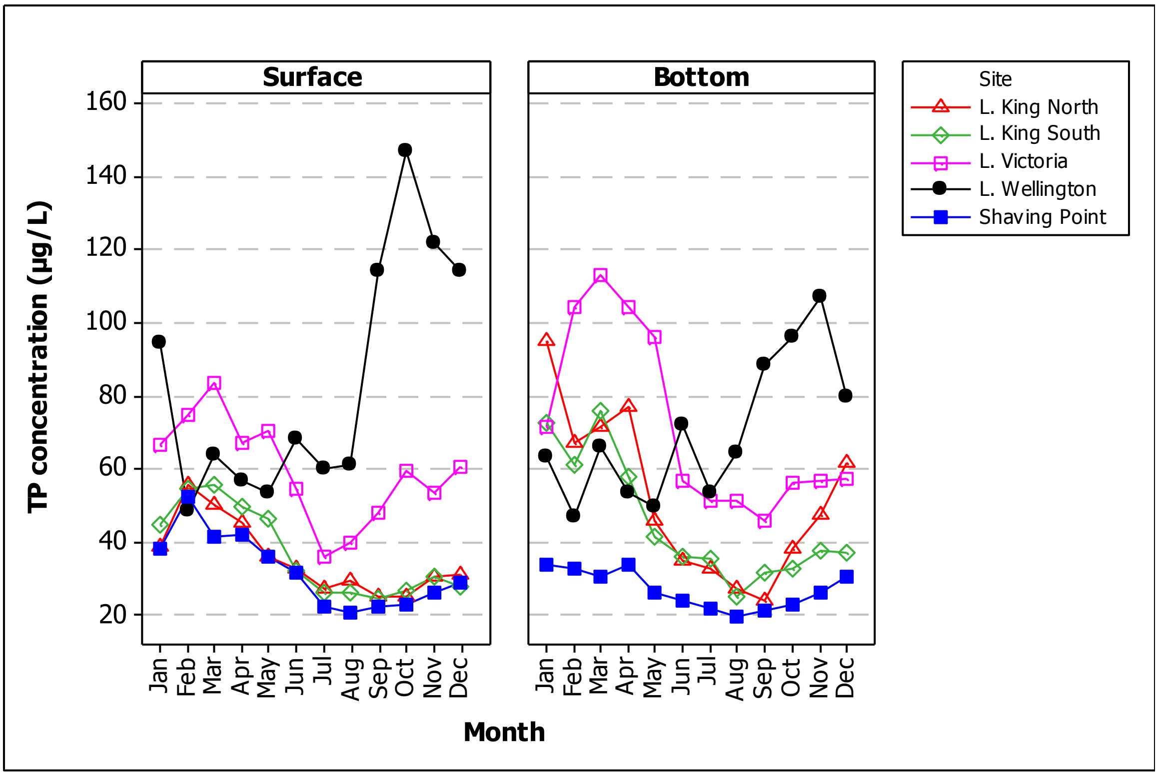

Figure 47: Monthly median of total phosphorus

Surprisingly, the bottom waters at the Shaving Point site had a higher NFR concentration than the two Lake King sites, while the surface waters were within the same range.

For TP (figure 47), the same west-east gradient was evident for the second half of the year (June to December) when inputs are mostly dominated by river flows. From January to May, the gradient as well as the relationship between the two Lake King sites still existed, but the Lake Victoria site showed the highest concentration of TP. This aspect was emphasised in the bottom waters, where TP concentrations in February, March, April and May exceeded the surface concentrations by up to 30 µg/L. Lake Victoria during those months becomes a hot spot for bottom phosphorus release.

$PO_4$ (figure 48), which is biologically available, showed a very similar pattern, with concentrations in Lake Victoria being the greatest from January to June, and bottom concentrations far exceeding surface concentrations. Bottom levels of $PO_4$ were also significantly higher than surface concentrations in Lake Victoria and King. This pattern for TP is likely due to an increase in nutrient release occurring around the Lake Victoria site, triggered by the decomposition of organic matter. Fine nutrient (organic) rich sediments settle around the Lake Victoria site when the Lake Wellington waters mix with more saline Lake Victoria waters. Decomposition of the organic matter accumulating at the site will consume a lot of the oxygen present at the bottom of the water column. This will trigger a release of phosphorus previously bound to the sediment. Figure 49 shows the monthly distribution of $PO_4$ and associated dissolved oxygen concentration at the Lake Victoria site bottom waters. It can be observed that when the concentration of $PO_4$ is high, the dissolved oxygen concentration does not appear to be always low. A lag effect between $PO_4$ and dissolved oxygen concentration can explain this discrepancy. $PO_4$ is likely to remain high while dissolved oxygen concentration rises, as dissolved oxygen fluctuates more quickly than the $PO_4$ concentration. In addition, dissolved oxygen is measured at half a metre from the bottom and could potentially not accurately represent the concentration of oxygen in the interstitial water of the sediments.

Cook et al. (2010) and Longmore and Roberts (2006) have shown that low dissolved oxygen levels alone could not fully explain the release of phosphorus from the sediment, and that benthic metabolism could play a significant role in the process. Lake Victoria could be a location where benthic activities in association with low dissolved oxygen concentrations could induce significant release of phosphorus from the sediment, but no data on benthic metabolic rate was available.

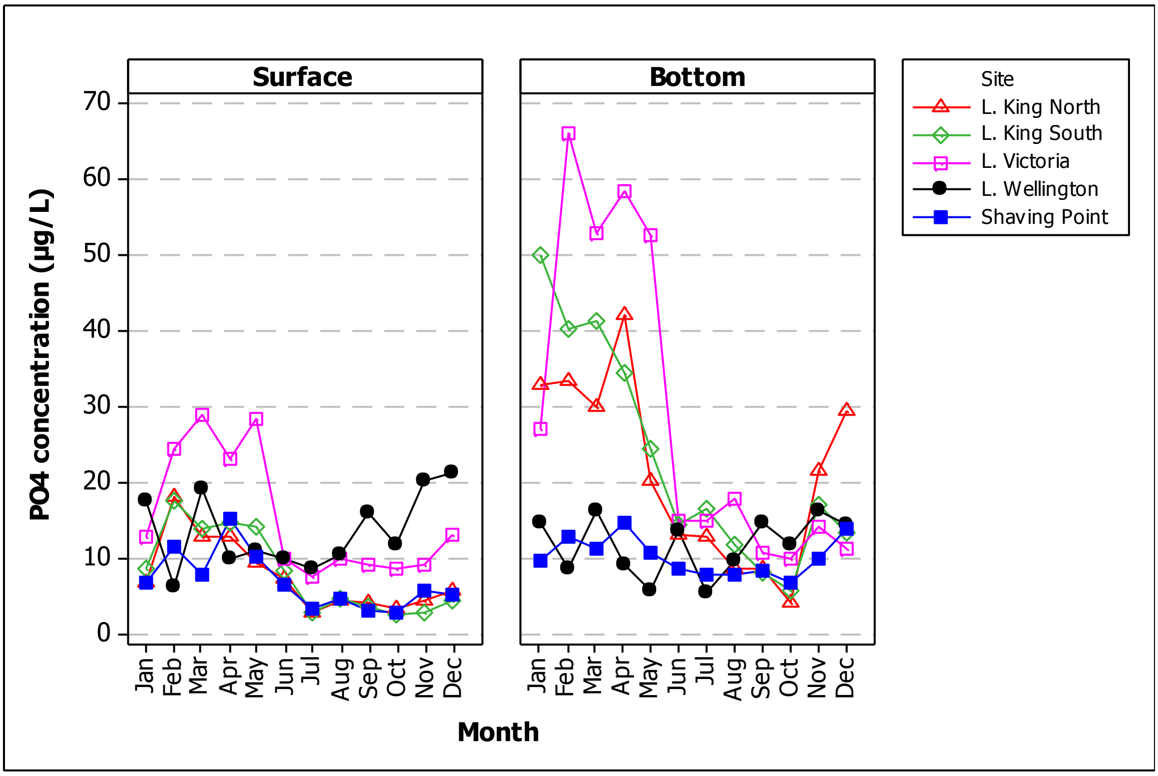

Figure 48: Monthly median of $PO_4$

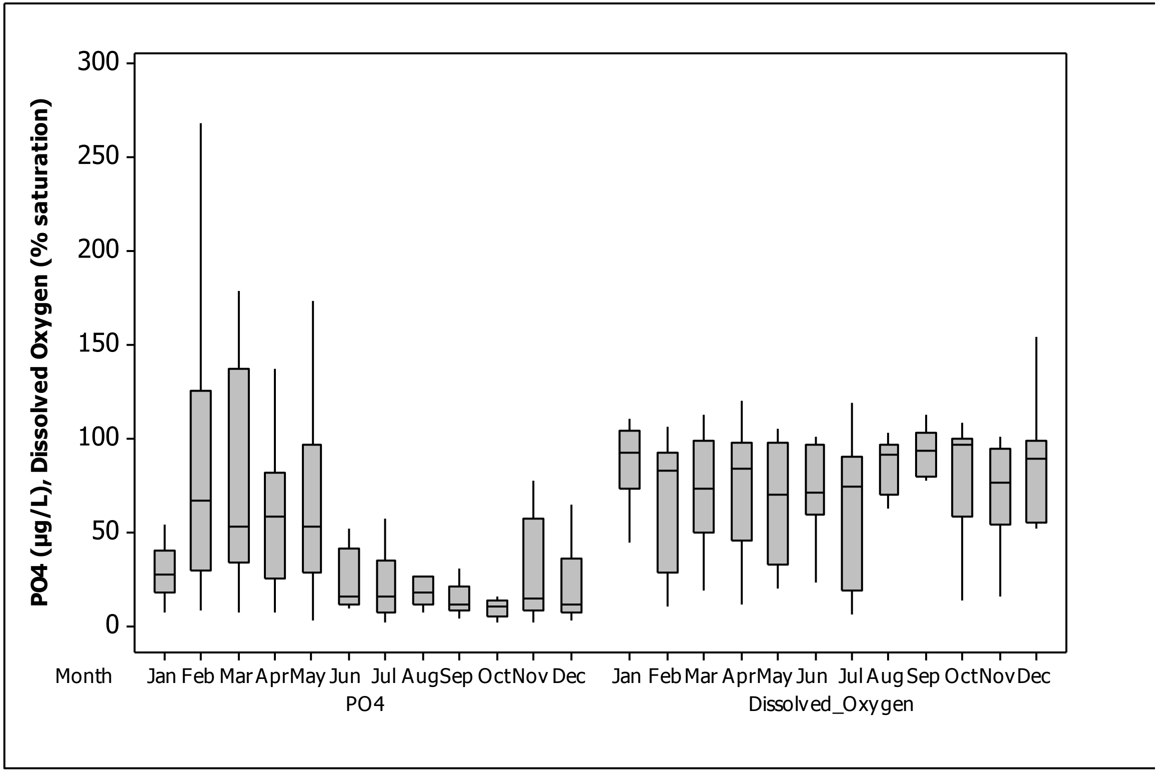

Figure 49: Boxplot of dissolved oxygen and $PO_4$ for bottom waters, at the Lake Victoria site

Oxidised nitrogen (NOx) concentrations in surface waters were very stable across the months and very similar amongst sites (figure 50). However, bottom concentrations of NOx showed an east-west gradient with the lowest levels generally observed in Lake Wellington, and Shaving Point exhibiting the highest concentrations. NOx concentration in bottom waters reached a peak in Lake Victoria, Lake King and at the Shaving Point site during late autumn/early winter (May to July). A previous study (EPA 2010) identified ocean waters as a significant source of NOx during the winter months. This could partly explain the trend observed in the present data.

The very sharp increase in December at the Lake Wellington site appears not to be due to error or artefacts in the data set. Figure 51 shows the monthly variability of $NO_x$ concentrations at the Lake Wellington site for the top and bottom waters. A clear increase in the variability of $NO_x$ concentration was visible for the second half of the year for both surface and bottom waters and could be explained by storm inputs. However, the bottom waters exhibited concentrations much higher than the surface waters and suggest sediment inputs. Further investigation is needed to explain what processes are driving the concentration of $NO_x$ at this site.

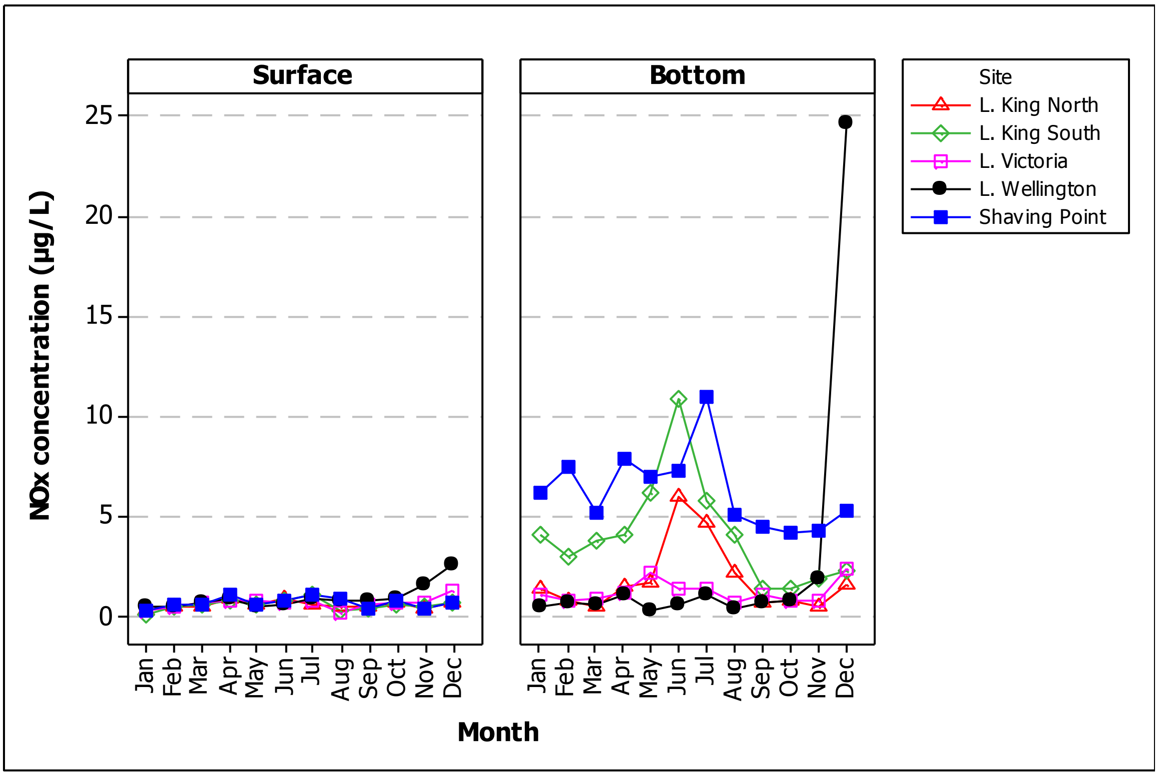

Figure 50: Monthly median of oxidised nitrogen

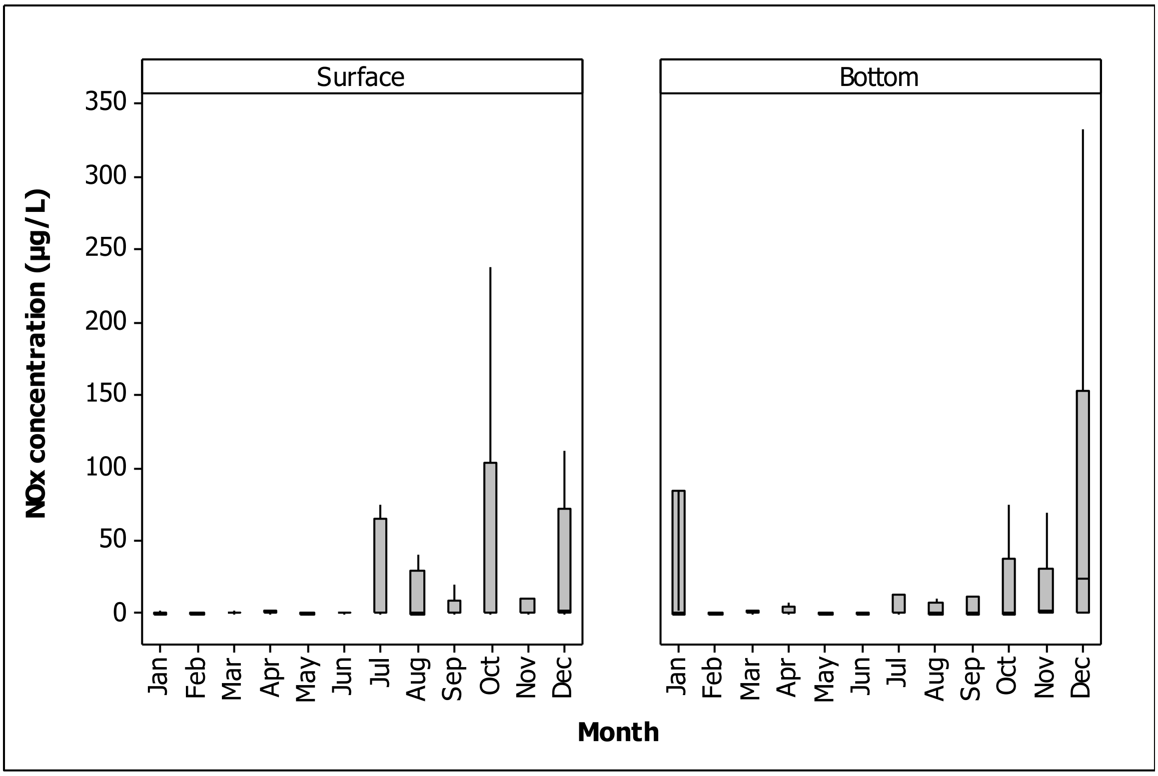

Figure 51: Boxplot of oxidised nitrogen at the Lake Wellington site

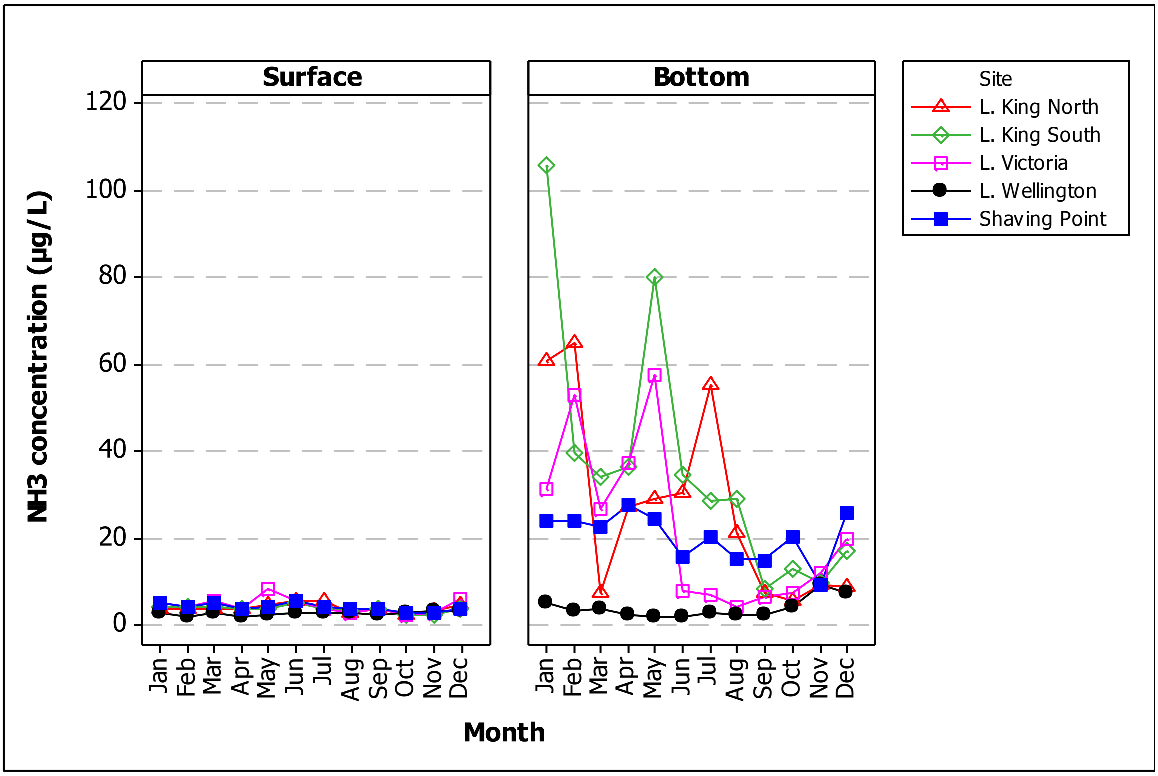

Figure 52: Monthly median of ammonia

Ammonium levels in surface waters generally showed a similar pattern to NOx. However, bottom concentrations varied greatly both spatially and temporally (figure 52). Lake Wellington surface and bottom waters exhibited similar concentrations all year round reflecting its well mixed state. All the other sites showed a strong increase in bottom $NH_3$

concentration. In 2003, Longmore et al. showed that denitrification was drastically reduced when the dissolved oxygen level was below 5 mg/L. Denitrification is the process by which nitrogen is converted to nitrogen gas and released to the atmosphere. When the denitrification process is reduced, other forms of nitrogen will be produced (i.e. $NH_3$). Figure 53 clearly illustrates the relationship between $NH_3$ and dissolved oxygen concentration, with the highest level observed when dissolved oxygen concentration is below 5 mg/L. The reduction in denitrification explains why the highest levels of $NH_3$ in bottom waters were observed in Lake King and Lake Victoria, as those sites are deep enough to experience salinity stratification and anoxia. The gradient in intensity of $NH_3$ release and oxygen depletion is widely influenced by water residence times. Sites with high residence times (i.e. Lake King North) will experience the highest $NH_3$ releases and lowest oxygen levels.

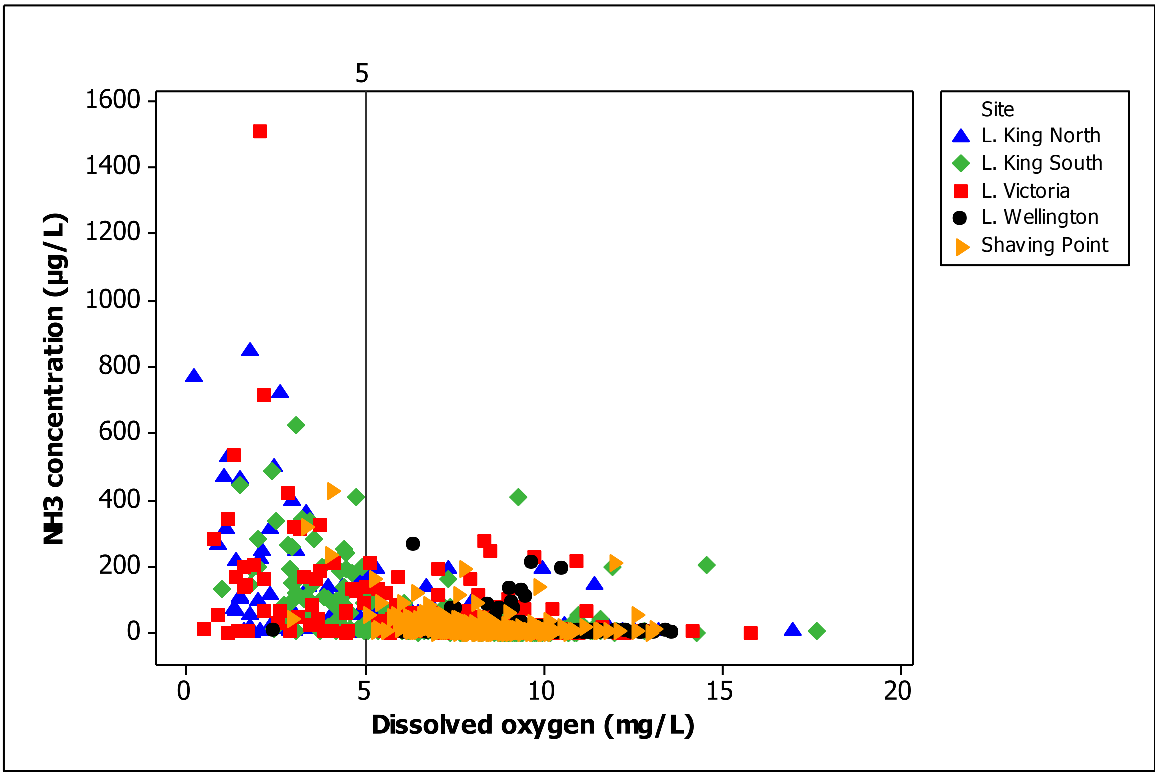

Figure 53: Scatterplot of ammonia versus dissolved oxygen for the bottom waters at all sites

The tendency for bottom waters of some of the monitoring sites to be hypoxic or anoxic at some times during the year is obvious from figure 54, where the Lake King North, South and Victoria sites showed periods with low dissolved oxygen levels. This was especially true during the summer months and is likely due to calmer conditions promoting salinity stratification. Lake Wellington bottom waters, in contrast, appeared to be fairly well oxygenated all year round. The Shaving Point site experienced some periods of low oxygen saturation.

For the surface waters, oxygen levels were around or above saturation, indicating that the level of oxygen in the surface water of the Gippsland Lakes was at a healthy level suitable to support aquatic life. The super saturation observed in summer at all sites but Lake Wellington was due to a high level of primary productivity.

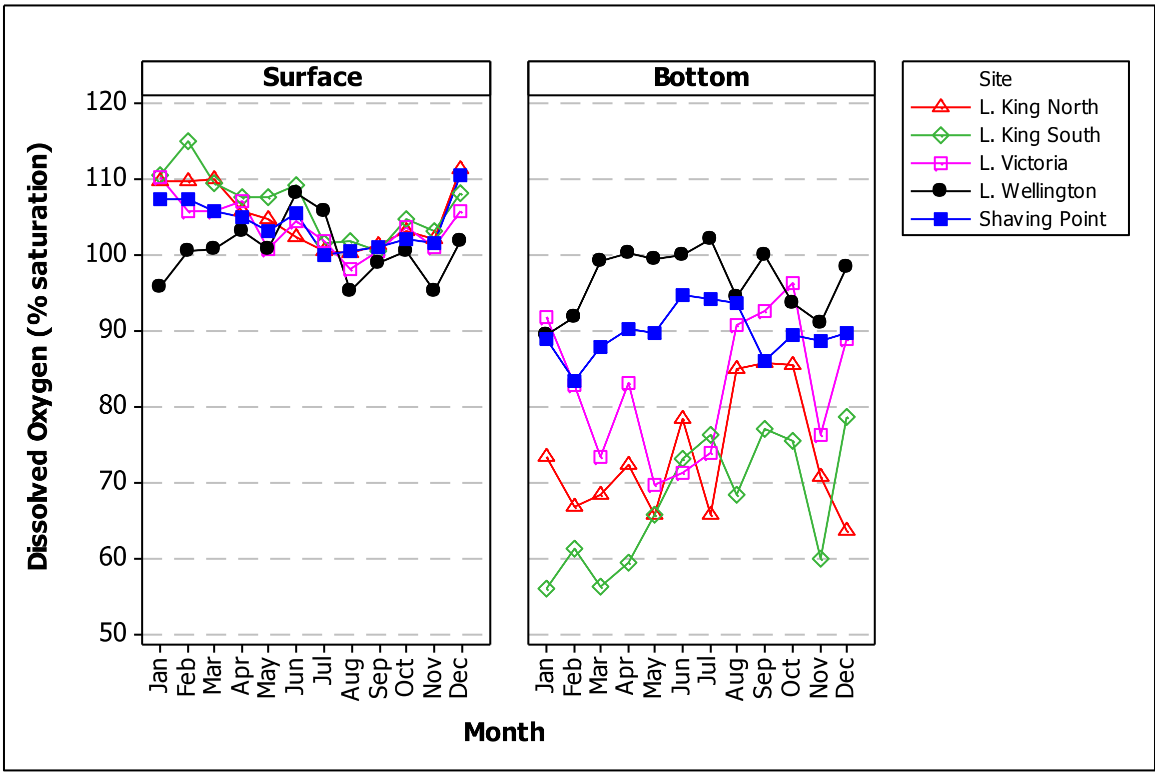

Figure 54: Monthly median of dissolved oxygen

This high level of productivity is reflected in figure 55 with most sites showing a significant increase in chlorophyll-*a* concentration in summer. As a result of the strong nutrient gradients noted earlier, a strong chlorophyll-*a* gradient is also observable across the Lakes system, especially in surface waters, with Lake Wellington having the highest concentration and Shaving Point the lowest (figure 55). Again, the two Lake King sites had very similar behaviour all year round for both surface and bottom waters.

Temperature follows a clear seasonal pattern (figure 56). Surface temperature at the Lake Wellington site was the coldest all year round, whereas the bottom was warmer than most sites in summer. Surface and bottom temperatures in Lake Wellington were very homogeneous, certainly due to the fact that it is well mixed. In winter, all other sites were slightly warmer than the Lake Wellington site, with bottom waters warmer than the surface due to the incursion of denser, warmer marine water acting like a thermal buffer.

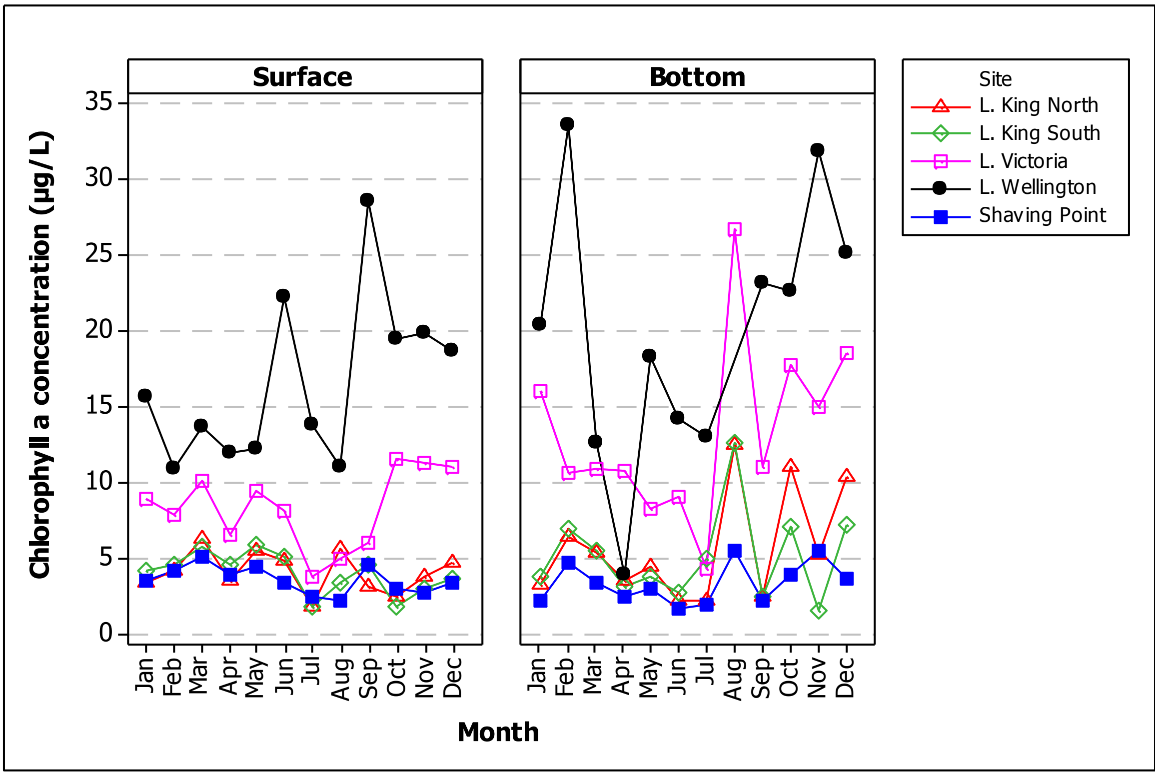

Figure 55: Monthly median of chlorophyll-*a*

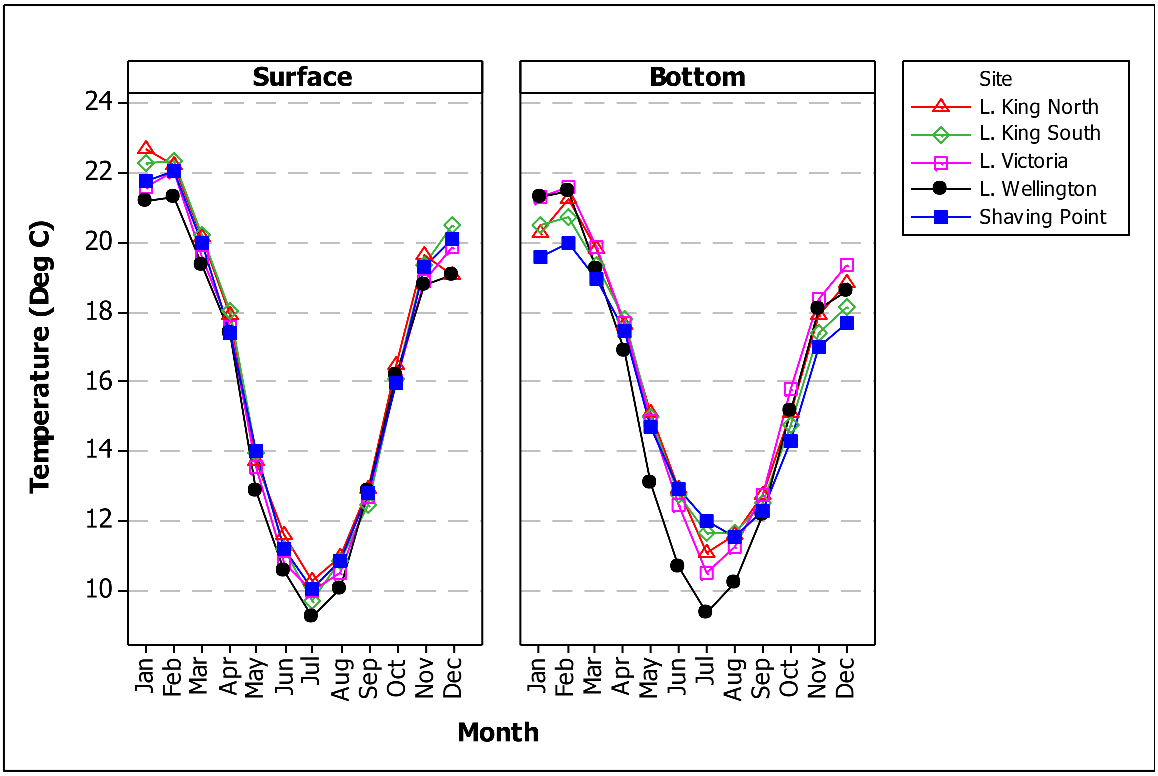

Figure 56: Monthly median of temperature

## Appendix E: SEPP compliance assessment framework