Cyanobacterial Issues in the Lake Powell / Torbay Inlet Drainage System
Prepared for the Water and Rivers Commission
Western Australia

By John A. Adeney

CSIRO Land and Water, Perth
Technical Report 44/01, May 2001
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Cyanobacterial Issues in the Lake Powell / Torbay Inlet Drainage System

EXECUTIVE SUMMARY

The Lake Powell/Torbay Inlet is a eutrophic drainage/coastal lake system that consists of three interconnected drainage systems operated at three different water levels. An intermittent sand bar effects drainage of the system via Torbay Inlet, which ultimately drains to the Southern Ocean.

Cyanobacteria blooms (Anabaena, Anabaenopsis, Nodularia, Oscillatoria) and chlorophytes in Lake Powell and Marbellup Brook in recent years have caused concern to residents and affected tourist potential. A combination of factors influence the occurrence of phytoplankton in these systems. The release of nutrients from sediments and dissolved oxygen (DO) levels are influenced by the supply of labile organic carbon and the presence of saline conditions in the water column the latter which may induce displacement of shallow, nutrient-enriched porewaters. In addition, the presence saline waters become important during periods of restricted circulation and/or low wind conditions. The suppression of diurnal overturn due to prolonged stratification particularly during summer, leads to the development of high concentrations of dissolved nutrients in bottom waters.

Marbellup Brook originally flowed into Lake Powell. Construction of an earthen bank (termed a “Plug”) across the Brook diverts water to Torbay Inlet. Limited water is allowed to enter Lake Powell through the Plug. Saline stratification occurs throughout Marbellup Brook below the Plug. This saline layer is the result of seawater entering Lake Marbellup from occasional high marine tides. The saline layer is not evident in Lake Powell. Management of the volumetric capacity of the three drainage systems are required to ensure that both the local salmon fishing and the seed potato industries can operate. Currently the Water Corporation endeavours to ensure that the low-lying agriculture land does not remain inundated after rainfall for more than 72 hours. Nutrient fluxes and their possible effects on phytoplankton growth have not been incorporated into the Water Corporation’s operating program.

The release of excess water from Lake Powell and Marbellup Brook depends on intermittent opening of the sand bar at Torbay Inlet. Early settlers identified the importance of the sand bar and constructed floodgates, which are now in ruins. Subsequent engineering works improved drainage but exacerbated phytoplankton growth due to low seasonal flows in summer and excessive nutrients. Water level and volumetric capacity has to be managed between the three drainage systems (Marbellup-Torbay Inlet system, Lake Powell-Grasmere Drain and the North Creek Drain-Maranup Lagoon system) to ensure that the local salmon fishing and seed potato industries can operate in environmental harmony with local residents.

It is recommended that a coupled nutrient balance/predictive hydrodynamic model be constructed to incorporate nutrient and physical factors to predict phytoplankton growth. With This model will allow the assessment of different management scenarios and prior to small- and large-scale trials and as a tool to monitor routine implementation. Construction of a model will also allow the development of a decision framework for factors such as water level(s) and flow, stakeholder input, the introduction of saline water and the timing and extent of application of nutrient reduction strategies. Parameters required to construct a coupled nutrient balance/predictive hydrodynamic model are discussed below:

Nutrient budgets/biological parameters

Internal nutrient loadings and extent of nutrient recycling: Estimates of internal nutrient loadings and extent of nutrient recycling are required for Lake Powell and Marbellup Brook.
Sediment cores and selected use of in-situ benthic chambers is recommended to determine the extent of nutrient recycling and nutrient release from bottom sediments.

External nutrient loadings: Broad-scale estimates of external nutrient loadings can be estimated on an annual basis. However, these loadings are based on infrequent (fortnightly or greater) water sampling, estimated and median flow rates. Refined estimates over a range of flow conditions and key external sources are required since nutrient inputs will be related to seasonal agricultural activities and/or rainfall frequency.

Nutrient export: The extent of nutrient export from both Lake Powell and Marbellup Brook is unknown. Estimates of nutrient removal through the penstocks to the Marbellup High Level Drain are required as water can leak through the penstocks from Marbellup Brook.

Influence of zooplankton: Predation of phytoplankton and the extent of nutrient recycling as a consequence of Daphnia grazing are not known. Zooplankton can feed partly or wholly on phytoplankton and bacteria and can influence species’ composition and phytoplankton succession. Zooplankton can also release nutrients, which may contribute to phytoplankton growth. Reports on zooplankton indicate that Australian native zooplankton cannot consume cyanobacteria at rates required to control phytoplankton blooms.

Nutrient bioassays: Nutrient bioassay measurements could be undertaken to establish the extent and frequency of nitrogen and phosphate limitation on phytoplankton growth in both Lake Powell and Marbellup Brook. Nutrient bioassays could be considered as a basis for the trial of a particular nutrient-reduction strategy and to gauge its effectiveness.

Physical parameters

Salinity: The effects of salinity on phytoplankton biomass and/or species composition and that of other biota in Lake Powell/Torbay Inlet/Marbellup Brook system are not known. The effect of saline stratification and density displacement of pore water has the potential to significantly augment nutrient flux from the bottom sediments into the overlying water column. Saline water introduced as part of the periodic inflows from Torbay Inlet may also influence phytoplankton species and succession and grazer (eg Daphnia spp) populations.

Mixing, stratification and hydraulic retention: Highly variable wind conditions occur in Lake Powell. This variability suggests that there may be periods of both pronounced mixing leading to sediment resuspension/mixing of nutrient-enriched bottom waters and quiescent conditions where significant thermal stratification and/or salinity stratification may persist. In contrast, because of the orientation of Marbellup Brook, static or low water flow and decreased wind influence due to tall overhanging vegetation, stratification is likely to be maintained for greater periods than in Lake Powell. Estimates of the hydraulic retention time for both Lake Powell and Marbellup Brook are also required as an essential parameter to predict and model the effectiveness of modification of flow into and out of Lake Powell.

Light limitation: Light limitation within the water body can affect phytoplankton growth. Cyanobacteria can through buoyancy regulation, position themselves in the water column to maximize their light uptake relative to other phytoplankton species, allowing a competitive advantage to certain species.

Potential management and remediation measures

Physical intervention/modification of flow regime

Modification of flow regime: Increased flows (periodic flushing) have the potential to reduce phytoplankton growth by reducing (via maintenance of oxidizing conditions) diluting and
partially exporting the internal sediment nutrient load, increasing turbidity (reducing light) and maintaining a changing water environment. Cyanobacterial dominance has not been observed in lakes where the hydraulic retention time is less than five days (Scheffer, 1998).

**Linking Lake Powell with North Creek Drain:** In linking Lake Powell to the North Creek Drain, water from Grasmere Drain would pass through Lake Powell to the North Creek Drain and onto Torbay Inlet via the Manerup Lagoon to improve mixing and flushing. Re-routing of water could only occur when the ocean sand bar has been breached and during low marine tides. Only limited mixing and flushing in Lake Powell is likely to result because of the exit drain would be relatively close *i.e.* 1 km from the Grasmere Drain entry point, reducing the possible loss of nutrients and phytoplankton biomass. As well, the capacity of the siphon, under the Marbellup High Level Drain may limit water flow. Because the North Creek Drain is linked to the Manerup Lagoon, there is also the possibility of phytoplankton contaminated water entering the lagoon. With a potential of creating further phytoplankton blooms. Seed potato farmers at Grasmere may benefit via the control of sub-soil moisture before planting.

**Removing the Marbellup Plug and linking Lake Powell to North Creek Drain:** Removal of the Marbellup Plug has been proposed to increase water flow through Lake Powell to the North Creek Drain and to the Manerup Lagoon. This modification would reduce the hydraulic retention time of water in both Lake Powell and Marbellup Brook. Increased flow would occur when the level of Lake Powell was lower than Marbellup Brook at Elleker, allowing Marbellup Brook to be flushed to the North Creek Drain. Control gates or penstocks would be required at the Marbellup Brook/Lake Powell entrance but would allow improved control of water levels and flows. Benefits would be a possible reduction in hydraulic residence time leading to a reduction in phytoplankton concentrations. The possibility of creating further phytoplankton blooms in Manerup Lagoon is high.

**Amalgamation of High Level and Mid Level drainage systems:** Construction of levee banks have been proposed around Lake Powell (Anonymous, 1995) so that the high water level system (Marbellup Brook/Torbay Inlet) can be synchronised with the mid water level system (Grassmere Drain/Lake Powell). Both systems would operate at a common water level and would simplify operational requirements. However, water flow in the Marbellup Brook below the “Plug” after levee construction may not be significantly greater than that allowed by the current “Plug”. Benefits would be the maintenance of a water level higher than current practice in Lake Powell (as desired by Grasmere seed potato farmers), removal of the “Plug” in Marbellup Brook, and removal of penstocks at Bridge 45. Part of this management option would be similar to that operating before the Marbellup High Level Drain was constructed.

**Re-design of Marbellup Brook:** Various locations in the Marbellup Brook are lower than the Marbellup Plug. Relatively high concentrations of nutrient are released at the depressions that are subject to periodic anoxia within the Brook. Therefore, a remedial solution is to infill the Brook to remove deep depressions. Any consequent reduction in soluble nutrients may be insufficient to reduce excessive phytoplankton growth.

**Management of the sand bar:** The timing of the breaking of the sand bar affects the water levels and drainage characteristics of the entire drainage system. The intermittent closure of the sand bar prevents the Water Corporation from being able to maintain adequate flows to reduce phytoplankton problems. To meet the requirement that low-lying agricultural land in the Cuthbert and North Creek areas does not remain inundated for more than 72 hours, the WA Water Corporation has to ensure that sufficient volumetric capacity is maintained within the drainage system. If this is close to being exceeded, the sand bar has to be opened manually. The gradual release of dark coloured water from Torbay Inlet using a submerged pipe and/or manifold (to ensure dilution) may alleviate this problem which is perceived to affect the local salmon fishing industry. A permanently opened sand bar would assist the Water Corporation to increase flows to remove occasional large quantities of drainage water.
Particular caution must be exercised when opening the sandbar for extended periods and in particular in the presence of high tides as the uncontrolled influx of seawater may lead to adverse accumulations of saline water, undesirable changes in biota and displacement of local shallow groundwater. The introduction of seawater could only be used as a short-term measure to partially flush Torbay Inlet and/or Lake Powell and prevent the growth of salt-sensitive phytoplankton species.

**Nutrient stabilisation**

*Alum treatment:* Alum can be added to water to form a colloidal aluminium hydroxide floc which binds both dissolved and particulate forms of phosphorus. It is unlikely that the use of this method in natural waters will gain regulatory approval because of the potential of aluminium toxicity.

*Phoslock™ treatment:* The use of a modified clay (Phoslock™) developed by CSIRO and the Water and Rivers Commission offers another form of phosphate stabilisation and reduction. The modified clay can be applied as a slurry over the surface of the lake and allowed to settle. The soluble phosphate in the water column and the soluble phosphate (FRP) released from the sediment is retained by the modified clay under a wide range of environmental conditions.

*Sediment oxidation:* Sediment oxidation has been used to reduce internal phosphate release from sediments. Calcium nitrate is injected into the upper sediments to stimulate loss of nitrogen by oxidation and ultimately denitrification. Potential benefits include loss of organic matter, oxidation of iron compounds and inactivation of phosphorus by sorption to the oxidised iron (Ripl, 1994). Potential problems may occur if not all of the nitrate is consumed or is rejected from the sediment into the water column by groundwater flow. Excess nitrate may during periods of N-limitation, lead to an increase in phytoplankton biomass.

*Artificial destratification:* It is likely that the presence of a persistent saline lower layer over the summer period in the Marbellup Brook and/or Lake Powell, leads to the production of significant concentrations of dissolved nutrients. Artificial destratification of the water column would lead to increased bottom water dissolved oxygen concentrations, a likely consequent reduction of nutrient release and an improvement of habitat for biota. Destratification is usually accomplished by bottom-mounted bubblers or mechanical mixers.

**Catchment management**

The cumulative effect of land clearing and fertilisation appears to have lead to nutrient-enriched sediments in Lake Powell and Marbellup Brook. The decline in excess nutrients in soils is likely to occur over decades. Urgent and intensive efforts as part of a long-term catchment management strategy are required to address the input of catchment nutrients. Efforts are currently in progress to introduce protection or rehabilitation of vegetation along both major and minor streamlines along the Five Mile and Seven Mile creeks in the Torbay Inlet Catchment to reduce nutrient loss from farmland (Green Skills, 2000).

**Biomanipulation**

The basis of biomanipulation involves the introduction of selected fish species at predetermined numbers consume the zooplankton and phytoplankton as a food source. A CSIRO trial is underway in two reservoirs in Queensland to investigate the suitability of the concept for phytoplankton control (Matveev, 1998). Biomanipulation may only have a limited application and impact due to the seasonally open system behaviour of the Torbay Inlet/Marbellup Brook/Lake Powell system.
1.0 INTRODUCTION

Periodic algal blooms in Lake Powell and the Marbellup Brook, below the Marbellup Plug (Figures 1 and 2) have reached unacceptable levels. Algal scum and offensive odours produced by decomposing phytoplankton on both water bodies are affecting the life of local residents. Nuisance midge populations have also occurred. Cyanobacterial (blue-green algae) blooms have also been reported in the adjacent waterways of Manerup Lagoon and the Torbay Inlet. These areas have considerable tourist potential.

The cyanobacterial blooms in Lake Powell and Marbellup Brook have been identified as primarily of *Anabaena circinalis*, *Anabaena spiroides*, *Anabaenopsis sp*, *Nodularia spumigena* and *Oscillatoria sp* (Evangalisti, 1998). *Microcystis sp* have also been reported (Water and Rivers Commission, 1999, 2000). All reported blooms have exceeded the ARMCANZ guidelines of 20,000 cells/ml for recreational water use. There is no recorded analysis of algal toxins from these blooms. The light winds (<10 km/hr) during the summer period from the southeast direction cause wind-accumulated scum to develop on the western shoreline of Lake Powell and to the northern end of the Marbellup Brook below the Marbellup Plug.

Lake Powell and the Marbellup Brook are components of the Lake Powell-Torbay Inlet Drainage System (also known as the Torbay Drainage District). The drainage systems that are managed by the Water Corporation of Western Australia (Figure 3) have been described in a number of reports (Hodgkin *et al* 1990, Evangalisti, 1998)

Following considerable local resident concern, the Water and Rivers Commission and CSIRO Land and Water began monitoring Lake Powell and Marbellup Drain for nutrients and phytoplankton. This report examines the causes of cyanobacterial blooms and options for their control in Lake Powell, Marbellup Brook, and in the drain leading to penstocks (flood gates) at Bridge 45.

2.0 SYSTEM CHARACTERISTICS

2.1 Ecological significance of the Torbay Inlet System

Before engineering works were undertaken in the 1950’s, the Torbay Inlet system consisted of a series of interconnected lakes and lagoons that operated at a common water level. These lakes and lagoons included Torbay Inlet, Manarup Lagoon, North Creek, Lake Powell and the lower reaches of Marbellup Brook (see Figure 3). Hydrologically, these components functioned as storages and slowed the velocities of floodwaters. Over the winter period, the water levels gradually rose with excess water collecting in the wetlands until the sand bar at Torbay Inlet was breached to release water to the ocean.

Lake Powell is listed on the Register of the National Estate, Australian Heritage Commission, as part of the Lake Powell Nature Reserve (Database No 018037). The Lake is under the control of the Department of Conservation and Land Management of WA. The nature reserve is an important feeding and breeding area for waterbirds (51 species) and a breeding area for several migratory bird species. Several reed islands have formed in the centre of Lake Powell. More than 30 species and 1000 individuals regularly inhabit the Lake Powell area during March and May of each year (Anon.1999).
Figure 1. Marbellup Brook algal bloom reported in February 1998 at Site MB6.

Photo courtesy of Mr John Blayney-Murphy, Elleker

Figure 2. Marbellup Brook algal bloom reported in April 2000 at Site MB4

Photo courtesy of Ms Julie Pech, Water and Rivers Commission, Albany
Schools of salmon have been reported, anecdotally, by fishermen to turn away from the coast when they come into contact with dark coloured water flowing from Torbay Inlet. The dark coloured organic matter in the water flowing from the Inlet also prevents the fishermen from locating schools of salmon.

2.2 Tourism

The Torbay Inlet system is increasingly becoming a focus for tourism with an increasing number of weekend chalets being established for bushwalking, fishing and surfing activities. Water from Lake Powell is considered to have entered Torbay Inlet and caused blooms to occur (G Bastyan pers.comm.). The possibility of water containing cyanobacteria entering Maranup Lagoon by passing through the penstocks (floodgates) by leakage, or by entering the North Creek Drain is recognised by local water management authorities. Many holiday homes and fishing cabins overlook the Maranup Lagoon.

Figure 3. Location map of Torbay Inlet, Manerup Lagoon, Marbellup Brook and Lake Powell.
3.0 PHYSICAL SETTING

3.1 Landscape

The landscape consists of gently undulating plains developed predominantly on tertiary sediments with occasional granitic hills. Soils are commonly duplex with shallow grey acidic siliceous sands overlying laterite and clay in the higher landscape and sands and sand gravels at lower elevations. Valleys often consist of deep sands (Weaver et al, 1998).

3.2 Catchments within the Torbay Sub Catchment

The major catchment is known as the Torbay Sub Catchment, which is subdivided into the Torbay Creek Catchment, the Marbellup Brook Catchment and the Seven Mile Creek Catchment (Figure 4). Characteristics of these catchments are given in Table 1. Pan evaporation of the Marbellup Brook Catchment is 1370 mm/annum (Public Works Department, 1984). The Five Mile Catchment is not within the drainage area of the Torbay Sub Catchment but is drained by the Five Mile Creek to the Five Mile Drain and then to the Seven Mile Creek.

Figure 4. Map of Lake Powell – Torbay Inlet Catchments and Drainage Systems

A = Torbay Catchment
B = Marbellup Brook Catchment
C = Seven Mile Catchment
D = Five Mile Catchment
E = Cuthbert Drainage District

The Five and Seven Mile Catchments are 60% cleared with pastoral activities predominating. Groundwater flow is from the North to the South, with upward leakage from the aquifer zone in the Marbellup Brook valley contributing to flow in Marbellup Brook. Groundwater levels
south of Lake Powell are 1–2 m AHD above sea level. Occurrences of granitic outcrops south of Lake Powell prevent groundwater flow to the ocean. The discharge areas have not been accurately located (Ventriss, 1978). However, the relatively high rainfall (~920 mm/yr) suggests that surface flow effects dominate the flow and nutrient inputs into Lake Powell (pers. comm. R Ferdowsian Agriculture WA 1999).

The land below the Five and Seven Mile Catchments which surrounds Torbay Inlet is low lying, with Lake Powell and surrounding land about 0.5 to 1.0 m above mean sea level.

3.3 Major Streams and Drains

The Lake Powell-Torbay Inlet system originates from two creeks (Five Mile and Seven Mile Creeks), which lead to Lake Powell by the Grasmere Drain. The Marbellup Brook below the Marbellup Plug, and a penstock drain link Lake Powell with Torbay Inlet, via the Marbellup High Level Drain. Figure 5 shows the major drains that operate at the three AHD levels.

Each catchment is operated as a drainage subsystem but each subsystem can be operated independently using floodgates (penstocks) and pipes fitted with valves (flaps).

**Marbellup Brook - Torbay Inlet subsystem** This drainage subsystem links Marbellup Brook with Torbay Inlet and bypasses Lake Powell by the Marbellup High Level Drain. The Torbay Drain enters the Torbay Inlet from the Torbay Township west of Torbay Inlet. The gauging station and nutrient sampling point is about 10 km from entry to Torbay Inlet because of gradient requirements for the stream-gauging station. The Marbellup Creek - Torbay Inlet system operates at the highest water level (based on ADH) and is called the High Level Drainage system.

**Table 1. Characteristics of the components of the Lake Powell / Torbay Inlet Drainage System.**

<table>
<thead>
<tr>
<th>Location</th>
<th>Mean Annual Flow (ML)</th>
<th>Rainfall (mm)</th>
<th>Length (km)</th>
<th>Area (ha)</th>
<th>Cleared (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torbay Sub Catchment</td>
<td>1,000</td>
<td>278,000 (1)</td>
<td>71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seven Mile Catchment</td>
<td>2,945</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Five Mile Catchment</td>
<td>1,384</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marbellup Brook Catchment</td>
<td>15.6 (2)</td>
<td>920</td>
<td>65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seven Mile Creek</td>
<td>3,611 (3)</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Five Mile Creek</td>
<td>993 (3)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>Torbay Main Drain</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Marbellup Brook</td>
<td>16,340</td>
<td>15</td>
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<td></td>
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</tr>
<tr>
<td>Grassmere Drain</td>
<td>5,711</td>
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<tr>
<td>Cuthbert Drain</td>
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<tr>
<td>Marbellup Drain</td>
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<td>Lake Powell</td>
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<td>Manerpup Lagoon</td>
<td></td>
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<tr>
<td>Torbay Inlet</td>
<td></td>
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</table>

(1) From Table 3.3, South Coast Regional Land and Water Care Strategy 1996
(2) Streamflow Records of Western Australia to 1982. (1984).
Lake Powell - Grasmere Drain subsystem This subsystem incorporates the Grasmere Drain and Lake Powell and the catchment area of Five and Seven Mile Creeks. Land is drained northeast of Lake Powell by the Five Mile and Seven Mile Creeks, which lead to the Cuthbert Drain, then to the Grasmere Drain, and then to Lake Powell. The Cuthbert Drain drains low-lying seed potato farms at Cuthbert. Lake Powell drains to Torbay Inlet by the Marbellup Brook-Penstock Drain to the Marbellup High Level Drain. Flow from Lake Powell is controlled by penstocks at Bridge 45 on the penstock drain. This system operates at a lower AHD relative to the Marbellup Creek-Torbay Inlet System. The system is also called the Middle Level Drainage System.

North Creek Drain-Maranup Lagoon system This subsystem drains the low-lying swampy land and seed potato farms in the Grasmere area. Maranup Lagoon receives this drainage water, which is released to Torbay Inlet usually when the ocean sand bar is open. Penstocks, which control the release of water, are located south of Maranup Lagoon. The system (also known as the Low Level Drainage system) operates at the lowest AHD water level of all the drainage systems.

Figure 5. Map showing the major streams, drains and different operating levels within the Lake Powell-Torbay Inlet Drainage systems.

A diagrammatic representation of the linkages between the three drainage subsystems is given in Figure 6.

3.3.1 Marbellup Brook

Marbellup Brook originally flowed to Lake Powell, but the construction of the Marbellup High Level Drain has reduced the volume of water entering Lake Powell. The length of the water body below the Marbellup Plug, (hereafter termed the “Plug”) is approx 1.6 km of
which approx 1.1 km is orientated north-south and approx 0.5 km is orientated east-west. Phytoplankton blooms have occurred over the entire 1.8 km length below the Plug.

The plug of the Marbellup Brook consists of a 30 cm (12-inch) metal pipe of approx 14 m length within an earthen bank. The duration of opening of this “Plug” over various years has been from 80 to 150 days from May to October. Dates of opening and closing are provided in Appendix 2, Table A2.1. The purpose of opening the “Plug” is to maintain a suitable water level in Lake Powell and to reduce nutrient concentrations and phytoplankton bloom development in the Marbellup Brook and Lake Powell (D Wright, Water Corporation WA, pers. comm. 2000). The “Plug” was installed in 1991, washed away in January 1992 and replaced.

A drain from approx midway along Marbellup Brook leads to Marbellup High Level Drain. This so called “penstock drain” has penstocks at Bridge 45 on the North Creek Road, about 1 km from the penstock drain/Marbellup Brook junction (Figure 7). After the penstocks, the penstock drain joins the Marbellup High Level Drain. The penstocks consist of four manually controlled gates constructed of wood. These penstocks have been observed to allow considerable amounts of water to pass through (G Bastyan, pers. comm. May 2000) when closed.

**Figure 6. Diagrammatic map showing linkages between the Torbay Catchment, the Marbellup Brook Catchment, and the Seven and Five Mile Catchment systems.**

The Torbay Main Drain drains the Torbay Catchment
The Marbellup Brook drains the Marbellup Brook Catchment
Grasmere Drain drains the Seven Mile (via the Seven Mile Creek) Catchment and the Five Mile Creek Catchment (via the Five Mile Creek and the Cuthbert Drain).
The North Creek Drain drains the low lying agricultural land closest to the coast
Figure 7. Map of Lake Powell, Marbellup Drain and the penstocks drain showing sample locations.

Lake Powell = LP1 to 3, Penstocks drain = MB8, Marbellup Brook = MB1 to MB7

Marbellup Brook is punctuated by a number of depressions so that saline water, being of a higher density, settles in these areas. The depths at each sampling site, estimated thickness of the unconsolidated sediments and the bottom contour of Marbellup Brook are shown in Table 2 and Figure 8. The unconsolidated nature of the Marbellup Brook sediments is shown in Figure 9.

Table 2. Estimated thickness of unconsolidated sediments and water depths (as at 2 November 1999) of Marbellup Brook at sampling sites.

<table>
<thead>
<tr>
<th>Sampling Site</th>
<th>Estimated sediment thickness (cm)</th>
<th>Water depths (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB1</td>
<td>80-100</td>
<td>1.3</td>
</tr>
<tr>
<td>MB2</td>
<td>50</td>
<td>0.7</td>
</tr>
<tr>
<td>MB3</td>
<td>200</td>
<td>0.7</td>
</tr>
<tr>
<td>MB4</td>
<td>50-70</td>
<td>1.0</td>
</tr>
<tr>
<td>MB5</td>
<td>5</td>
<td>1.0</td>
</tr>
<tr>
<td>MB6</td>
<td>100</td>
<td>1.6</td>
</tr>
<tr>
<td>MB7</td>
<td>0</td>
<td>0.8</td>
</tr>
<tr>
<td>MB8</td>
<td>50</td>
<td>1.2</td>
</tr>
</tbody>
</table>
3.2 Grassmere Drain, Cuthbert Drain, North Creek Drain, and Five and Seven Mile Creeks

Grasmere Drain carries drainage water from the Five Mile Creek, the Seven Mile Creek and the Cuthbert Drain. The Cuthbert Drain collects wastewater from seed potato farming areas. Average phosphate application rates are 80-90 kg P/ha (Weaver et al., 1998). Fertiliser application occurs at the time of seeding (November/December) with dual-purpose seeding/fertilising machinery. The clearing of land in the Cuthbert area has lead to the oxidation of the swamp soils, which contain a high concentration of iron sulphide (Register of the National Estate (1998). Agriculture WA has identified the presence of these acid-sulphate
soils. Lime is regularly applied to maintain potato seed production. North Creek Drain drains wetlands and low-lying agricultural land south of Lake Powell and leads to Maranup Lagoon passing under the Marbellup High Level Drain by pipes. Maranup Lagoon can be isolated (by penstocks) from the other drainage systems. Drainage of the sulphide-rich swampy soils has led to oxidation and acidification, causing a decrease of pH in North Creek Drain. Agriculture WA has identified these acid-sulphate soils and soil management programs are in place. Water quality data for the North Creek and Cuthbert Drain is provided in Appendix 3, Table A3.1.

Five Mile Creek (within the Five Mile Catchment) is sampled at Wonton Farm, in the southern (and lower) area of the catchment. The Five Mile Drain, at the lower end of the catchment, joins the Seven Mile Creek. Gauging and nutrient sampling began in June 1993.

Seven Mile Creek is sampled as a Department of Environmental Protection licensing requirement of Water Corporation’s Tree Farm at Gunn Road, in the northern (and elevated) area of the catchment (Figure 3). Gauging and nutrient sampling began in 1993. Monitoring is the responsibility of the WA Water Corporation. Seven Mile Creek is also stream gauged and sampled at Wonton Farm, in the southern (and lower) area of the catchment. Gauging and nutrient sampling began in July 1997.

3.3.3 Marbellup Brook above the Plug

Marbellup Brook meets the Marbellup High Level Drain that then leads to Torbay Inlet. Graphs of nutrient data of TN, TP FRP, N-NH₃ and Cl from Marbellup Brook are provided in Appendix 2, Figures A2.1, A2.2 and A2.3. Water samples were taken from a small weir on Marbellup Brook located north of Lower Denmark Road, approximately 2 km upstream of the “Plug” (see Figure 7). The average suspended solids concentration in 1979 was low (5 mg/L - Donnelly, 2000).

3.4 Receiving Water Bodies

3.4.1 Lake Powell

Lake Powell is a playa lake covering an area of 14.0 ha of which 12.6 ha is open water. The average depth is 0.5 m. The dimensions are 1.8 km long and 0.9 km wide with the longest axis being orientated primarily NW/SE. Anecdotal information indicates that deep-keeled yachts were sailed in the 1950’s (Evangalisti, 1998), suggesting a substantial sediment accumulation in the lake over the past five decades. Fringing vegetation is primarily of *Juncus* and *Scirpus spp.* No submerged macrophytes or microphytobenthos were observed during sampling.

Water enters Lake Powell from Grassmere Drain and from Marbellup Brook, only when the “Plug” is opened. Treated wastewater from the Timewell Road Treatment Plant (from 1995) is pumped to a land disposal site in the north (and elevated) area of the Seven Mile Catchment where it is distributed over pasture and onto the WA Water Corporation’s Tree Farm (Figure 7). Flow and nutrient measurement from the Tree Farm is recorded at Gunn Road.

3.4.2 Manerup Lagoon

Manerup Lagoon (see Figure 5) receives water from North Creek Drain. Limited nutrient information is available (Appendix 3, Table A3.2). Low pH values (3-4) were recorded during a “snapshot” assessment of nutrients throughout the Torbay drainage system in September 1998. The low pH values reflect the nature of the iron sulphide of agricultural soils that were once lake sediments. The average depth of Manerup Lagoon varies considerably but does not exceed 0.5 m.
3.4.3 Torbay Inlet

Torbay Inlet receives water from Marbellup Brook, the Torbay Main Drain and the Marbellup High Level Drain. Limited nutrient information has been collected on Torbay Inlet. Appendix 3, Table A3.3 provides physico-chemical data, nutrient and phytoplankton concentrations collected during this study. Cyanobacteria blooms were reported in Torbay Inlet before 1985 (Hodgkin et al., 1990). A bloom of *Nodularia spumigena* was reported in April 2000 that coincided with release of water from Lake Powell through penstocks at Bridge 45 on the Elleker Grasmere Road. The remnants of flood control gates (constructed in 1912), upstream of the Torbay sand bar, indicate that early settlers were endeavouring to control the entry of salt water into Manerup Lagoon and associated drains from the 1940’s.

4.0 WATER LEVEL MANAGEMENT

The Water Corporation controls water levels from each of the three systems at various times of the year to ensure that the low-lying agricultural land does not remain inundated for more than 72 hours.

Currently, the water levels of each water body are controlled, based on Minimum Base Level (MBL) and Critical Level (CL) as follows:

- Lake Powell not to exceed 1.0 m AHD MBL and CL
- Torbay Inlet not to exceed 1.4 m AHD MBL and CL
- Maranup Lagoon not to exceed 0.4 m AHD MBL and 0.2 m AHD CL

Minimum Base Level is that level necessary for flow to occur between each water body. Critical Level is that water level that must not be exceeded otherwise water overflow will occur over levee banks, retaining walls and flood control gates (penstocks).

Anecdotal evidence suggests that high water levels in Torbay Inlet can breach the ocean sand bar. However, breaching the ocean sand bar to release dark coloured (humic-rich) water between February and April can affect the local salmon fishing industry.

Lake Powell water levels exceeded Torbay Inlet levels for limited periods each year. Average number of days each year is 89, the longest period being 168 days in 1996/1997 and the shortest period being 21 days in 1999/2000. Thus there is limited opportunity to increase water flow from Lake Powell through the Marbellup Brook and penstock drains. The AHD level of Lake Powell has to be occasionally maintained at a higher level than the Torbay Inlet AHD to allow seed potato farmers to have moist land before planting. Currently water levels in the three systems are operated based on local experience. A draft management plan has been prepared by the Water Corporation (Wright, 1999).

5.0 INVESTIGATION METHODS

Routine sampling was undertaken in Lake Powell, Marbellup Brook and the penstock drain every second week from November 1999 to April 2000 and then every fourth week until June 2000. A preliminary sampling of these locations was also carried out in early October 1999.

5.1 Physical, chemical and biological measurement

Temperature, salinity and DO were recorded using a Hydrolab H20. Surface samples were taken to a depth of 15 cm. Bottom samples are taken with a submersible bilge pump fitted with a foot valve. Analyses were made of nitrate and nitrite (N-NO$_3$), ammonia (N-NH$_3$), total nitrogen (TN), filterable reactive phosphate (FRP), total phosphate (TP), chlorophyll a and
phaeopigments. Integrated samples for phytoplankton identification and cell counts were taken with a 40 mm diameter polycarbonate tube. Samples were preserved in Lugols solution for later microscopic identification by the Phytoplankton Ecology Unit, Water and Rivers Commission. The thickness of unconsolidated sediments in Marbellup Brook was determined manually from the sampling boat using a marked probe (see Figure 8).

5.2 Lake Powell

Water samples (LP1, LP2 and LP3) in Lake Powell were taken at surface and at the bottom of the lake. When only one sample was taken, the physical, chemical and biological values are included at both surface and bottom values. A further sample site, (recorded as MB8) in the penstock drain was also sampled routinely. Sampling sites in Lake Powell are given in Figure 7. Nutrient data, salinity and DO for Lake Powell are provided in Appendix 1, Table A1.1.1-3. Phytoplankton data is provided in Table A1.2. Cyanobacteria data is provided in Table A1.3. The monthly occurrence of the major species of phytoplankton is listed in Table 3.

Table 3. Summary of major phytoplankton occurrences (>20,000 cells/ml) in Lake Powell from November 1999 to June 2000.

<table>
<thead>
<tr>
<th>Month</th>
<th>Major phytoplankton species (&gt;20,000 cells/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov 1999</td>
<td>Nodularia spumigena</td>
</tr>
<tr>
<td>Dec 1999</td>
<td>Nodularia spumigena</td>
</tr>
<tr>
<td>Jan 2000</td>
<td>Nodularia spumigena</td>
</tr>
<tr>
<td>Feb 2000</td>
<td>Microcystis aeruginosa</td>
</tr>
<tr>
<td>Mar 2000</td>
<td>Nodularia spumigena</td>
</tr>
<tr>
<td>Apr 2000</td>
<td>Nodularia spumigena</td>
</tr>
<tr>
<td>May 2000</td>
<td>Nodularia spumigena</td>
</tr>
<tr>
<td>June 2000</td>
<td>Apedenalla sp</td>
</tr>
</tbody>
</table>

5.3 Marbellup Brook

Seven sites (MB1 to 7) were sampled in Marbellup Brook. A further sample site, (recorded as MB8) in the penstock drain was also sampled routinely. Figure 7 shows the sampling sites in Marbellup Brook and the penstock drain. The sample site of MB8 located approximately 200 m from the Marbellup Brook/penstock drain junction was selected since the site was the furthermost distance accessible. Nutrient and physico-chemical data is in Appendix 2, Table A2.2.1-10. The nutrient and physico-chemical parameters of Marbellup Brook show higher concentrations of FRP, N-NH3 and DO than values measured in Lake Powell. Additional sampling was carried out in Marbellup Brook as part of the Phoslock™ application trial from 14 April 2000. Nutrient and phytoplankton results from the treated area after this date have been excluded. Phytoplankton data is provided in Appendix 2, Figures A2.3.1-6, Tables A2.3.1-5 and as monthly occurrences in Table 4. Nutrient concentrations of TP, TN, TOC and S in the bottom sediments are provided in Appendix 2, Table A3.1.
Table 4. Summary of major phytoplankton occurrences (>20,000 cells/ml) in Marbellup Brook from November 1999 to June 2000.

<table>
<thead>
<tr>
<th>Month</th>
<th>Major phytoplankton species (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov 1999</td>
<td>Nodularia spumigena</td>
</tr>
<tr>
<td>Dec 1999</td>
<td>Anabaena circinalis</td>
</tr>
<tr>
<td>Jan 2000</td>
<td>Nodularia spumigena</td>
</tr>
<tr>
<td>Feb 2000</td>
<td>Microcystis incerta</td>
</tr>
<tr>
<td>Mar 2000</td>
<td>Microcystis incerta</td>
</tr>
<tr>
<td>Apr 2000</td>
<td>Nodularia spumigena</td>
</tr>
<tr>
<td>May 2000</td>
<td>Nodularia spumigena</td>
</tr>
<tr>
<td>Jun 2000</td>
<td>Chlorophyta</td>
</tr>
</tbody>
</table>

(1) Based on data provided by Phytoplankton Ecology Unit, Rivers and Water Commission

Table 5. Total Phosphorus in Marbellup Brook sediments.

<table>
<thead>
<tr>
<th>Sediment Sampling Site</th>
<th>TP (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB1</td>
<td>210</td>
</tr>
<tr>
<td>MB2</td>
<td>1160</td>
</tr>
<tr>
<td>MB3</td>
<td>81</td>
</tr>
<tr>
<td>MB4</td>
<td>810</td>
</tr>
<tr>
<td>MB5</td>
<td>120</td>
</tr>
<tr>
<td>MB6</td>
<td>460</td>
</tr>
<tr>
<td>MB7</td>
<td>1300</td>
</tr>
<tr>
<td>MB8</td>
<td>34</td>
</tr>
</tbody>
</table>

6.0 RESULTS

6.1 Lake Powell

Lake Powell sediment is characterised by a fine layer of consolidated black silt from 0-5 cm (Figure 10) above a grey sandy lower layer. Evangilisti and Associates (1998) report of a core taken from Lake Powell in February 1998 to investigate recent sedimentation. A transition was noted from grey sand to coffee coloured sediment at 80 cm. This colour change may mark the commencement of European land use and accelerated erosion. Consequently net sedimentation of up to 80 cm could have occurred in recent years i.e. from the early 1950’s and represents a net accumulation rate of ca 1.6 cm/yr.
Ten sediment samples, collected at randomly selected sites from Lake Powell, had an average TP concentration of 244 mg/kg. The range was from 95 to 980 mg/kg. However there was no simple relationship between sediment TP and location within Lake Powell.

**Figure 10. Sediment core from Lake Powell.**

Inflow from Lake Powell primarily comes from Grasmere Drain and from Marbellup Brook, when the “Plug” is open. Outflow from Lake Powell, travels along part of Marbellup Brook to the penstock drain. Fifteen years of water quality data from Lake Powell (Appendix 1, Figure A1.1) show that salinity concentrations have not increased, despite large fluctuations in the 1980’s. No chlorophyll data measurements were made over this period. Low pH levels of 3.5 were recorded from 1910 to 1940’s presumably as a consequence of the cultivation of low lying land around Lake Powell (Hodgkin *et al.*, 1990).

Intermittent samplings of phytoplankton have taken place in Lake Powell depending on the extent of public concern. The Water and Rivers Commission has issued official warnings of cyanobacteria counts being over ARMCANZ recreational guidelines of 20,000 cells/ml, for both Lake Powell and Marbellup Brook on 23 November 99, 14 December 99, 3 January 00 and 26 May 00.

Field monitoring staff reported that considerable sediment resuspension occurred at wind speeds greater than 15 km/hr (~8 knots) (G Bastyan *pers. comm*. 2000). The wind speed of 10 km/hr is exceeded 69% of the time from all directions from November to May as measured at the Albany Aerodrome, 9 km from Lake Powell (Bureau of Meteorology data). The frequency of winds less than 1 km/hr (defined as calm periods by Bureau of Meteorology) was 14% from November to May, suggesting that there were periods during which thermal stratification could develop. Turbidity measurements were not taken during the study.

**6.1.1 Nutrients**

Concentrations of nutrients showed similar patterns in both surface and bottom waters, with no significant differences (P = 0.05) between surface and bottom sample concentrations and
between sampling sites - LP1, LP2 and LP3. Hence Lake Powell can be regarded as being a well-mixed water body. All nutrient concentrations have been averaged for the three sites.

High concentrations of TP and FRP occurred early December, late January and in the mid to late April (Figure 11). The average percentage of FRP as a proportion of TP over these months was 11% and ranged from 2 to 30%. The concentrations of TN showed synchronous increases with N-NH$_3$ (Figure 12). Averaged concentrations of N-NH$_3$ ranged from 0.03 to 0.07 mg/L with two successive samplings on January and February exhibiting concentrations of up to 2.7 mg N-NH$_3$/L and constituting ~ 40% of the TN concentration. Conditions as reported by field staff when sampling in January and February indicate high turbidity as assessed visually with considerable zooplankton present. Winds during sampling ranged from the east to the south west at a speed of approx.18 knots ~ 33 km/hr. Wind of this speed would produce resuspended sediment and a standing wave in excess of the depth of Lake Powell. Salinity values reached a maxima (6.9 g/L) in early February with slightly elevated levels occurring on the sampling dates before and after, suggesting that strong south west winds may have promoted the distribution of salinity from Marbellup Brook.

**Figure 11. Averaged TP (mg/L) and FRP (P-PO$_4$ mg/L) data for Lake Powell from October 1999 to June 2000.**

Surface and bottom values on each sampling date have been averaged. Error bars = 1 standard deviation.
Figure 12. Averaged Total Nitrogen and Ammonia (N-NH₃) in Lake Powell from October 1999 to June 2000.

Surface and bottom values have been averaged. Error bars = 1 standard deviation. Between January and February 2000 N-NH₃ values reached 1.6 and 2.7 N-NH₃ mg/L.

6.1.2 Physical parameters

Surface and bottom measurements of dissolved oxygen (DO) were taken approximately every two weeks from November 99 to late June 00. The pH, DO and conductivity measurements showed similar patterns in both surface and bottom waters at all sites, LP1, LP2 and LP3 with no statistically significant differences (P=0.05). Hence, all physical parameters have been averaged for the three sites. The range of DO concentrations were 7.1-11.4 mg/L for surface samples and 5.6-11.8 mg/L for bottom samples. Average water temperatures peaked intermittently in early November, early February and mid April (Figure 13) with the range being from 16.9 to 23.7 °C.

6.1.3 Biological parameters

From November 99 to June 00, Lake Powell experienced a succession of phytoplankton blooms. These occurred in early November, mid December/January, February, mid to late April and continued through to June when sampling ceased (Appendix 1, Figures A1.2 and A1.3). Cell counts were carried by the Phytoplankton Ecology Unit of the Water and Rivers Commission as part of a state-wide program on the surveillance of harmful cyanobacteria.

The early November bloom was composed of diatoms (*Nitzchia sp*). Then followed a cyanobacterial bloom of a mixture of *Nodularia spumigena*, *Anabaena circinalis*, cf *Anabaenopsis*, straight-chained *Anabaena*, and *Pseudanabaena sp* in late November. Following the decline in cyanobacteria concentrations the chlorophyte concentrations (primarily *Ankistrodesmus sp*) then increased to 116,000 cells/ml by late December/early January, with a smaller increase in cyanobacteria and diatoms. By mid January the *Nodularia* bloom had declined and a very active population of zooplankton was observed. Examination of a water sample taken in mid-January showed that *Daphnia* constituted more than 70% of the zooplankton present. By mid February *Microcystis incerta* dominated and then throughout March, both *Nodularia* and *Microcystis* formed 67% of the total phytoplankton species present. The chlorophyte *Scenedesmus* was present in March, but at low concentrations. By late March/early April both *M. incerta* and *N. spumigena* continued to dominate. In late April cyanobacteria, and diatoms and chlorophytes concentrations increased. In May high
concentrations of *M. incerta* and *N. spumigena* (> 20,000 cells/ml) were maintained. By late June cyanobacteria bloom concentrations were maintained and diatoms, chlorophytes and chrysophytes appeared in bloom proportions.

Maximum chlorophyll a concentrations occurred in Lake Powell on late February (130 μg/L) and late April (220 μg/L). The summer seasonal average was 70 μg/L. Chlorophyll a concentrations during the study period are shown in Figure 15.

**Figure 13.** Averaged water temperatures (surface and bottom) in Lake Powell from October 1999 to June 2000.

![Temperature Chart](chart13)

Error bars = 1 standard deviation

**Figure 14.** Chlorophyll a concentrations (μg/L) in Lake Powell from November 1999 to May 2000.

![Chlorophyll a Chart](chart14)
6.1.4 Nutrient loads

Annual loadings of TN and TP were calculated from flow and nutrient data for the Five Mile Creek (January 98 to Jul 99) and Seven Mile Creek (Jul 97 to Oct 99) and for the Cuthbert Drain (May 98 to Jul 99). Estimated annual loadings to Lake Powell were 9.4 tonnes TN and 1.6 tonnes TP (Table 6). These should be regarded as tentative since they are based on a fortnightly water sampling regime and estimated and median flow rates (pers comm. A Maughan, Water and Rivers Commission, 1999).

Table 6. Estimated annual nutrient inputs to Lake Powell.

<table>
<thead>
<tr>
<th>Creek/Drain</th>
<th>Annual Flow (ML)</th>
<th>Annual loading (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>TN</td>
</tr>
<tr>
<td>Five Mile Creek</td>
<td>2,173</td>
<td>3,058</td>
</tr>
<tr>
<td>Seven Mile Creek</td>
<td>3,737</td>
<td>3,587</td>
</tr>
<tr>
<td>Cuthbert Drain</td>
<td>869</td>
<td>2,726</td>
</tr>
</tbody>
</table>

6.2 Marbellup Brook

6.2.1 Nutrients

Concentrations of nutrients generally displayed similar patterns in both surface and bottom waters, at all sampling sites – MB1 to MB8. Nutrient concentrations and physical parameters in surface and in bottom waters have been averaged for sites MB1 to MB7 from 6 November to 23 June 2000, and sites MB1, MB2 and MB3 for sampling dates after 13 April to 23 June 2000. Sites MB4, MB5, MB6 and MB7 were within the Phoslock™ treated site that was treated on 14 April 2000. (Phoslock™ treatment of Marbellup Brook, April 2000, Water and Rivers Commission, 2001, in prep). Site MB8, within the penstock drain was sampled up to 23 June 2000.

Average TN and TP concentrations (surface and bottom values averaged) increased (TN 0.4 to 1.6 mg/L, TP 0.16 to 0.21 mg/L) to mid March, with a ten-fold increase in TN (9.6 mg/L) and a five-fold increase in TP (4.5 mg/L) occurring in mid April (Figure 15). There were four occasions when elevated concentrations of N-NH₃ and FRP occurred in the bottom waters of Marbellup Brook. These were in early November, early December, late January and in the middle to late April. In early December the highest concentrations of N-NH₃ (0.3-2.1 mg/L) in the bottom waters were at MB1, MB2, MB3 and MB7 (Figure 16). By early February a further peak of N-NH₃ (0.12-1.9 mg/L) in the bottom waters occurred at all sites with a major N-NH₃ peak occurring at site MB6. By mid April very high concentrations (~8.1 mg/L) of N-NH₃ occurred in the bottom waters at sites MB1 and MB8. High N-NH₃ (~2.6 mg/L) concentrations remained at sites MB4 and MB5 up to late June. All sample sites exhibited elevated N-NH₃ concentrations, although at different times, during the sampling period, November 1999 to June 2000.

In early December there was increased concentrations of FRP (0.26 - 0.65 P-PO₄ mg/L), particularly at sites MB4 and MB8 (0.74-0.89 P-PO₄ mg/L). By late January FRP concentrations had also increased at sites MB1 and MB2. By mid April FRP concentrations had increased at site MB1 and at MB8 to about 2.7 mg P-PO₄/L (Figure 17). The very large increase in both N-NH₃ and FRP coincided with a major saltwater intrusion into the penstock
drain and then into the southern length of Marbellup Brook resulting in salinities of up to 30 g/L. Bottom water FRP concentrations exceeded surface water FRP concentrations by a factor of 3 to 40 times from November to June.

**Figure 15. Averaged Total Nitrogen and Total Phosphorus (mg/L) concentrations in Marbellup Brook from October 1999 to June 2000.**

Surface and bottom values at each sampling date averaged

**Figure 16. Contribution of ammonia (N-NH₃) from different sites in Marbellup Brook from November 1999 to June 2000.**

Maximum efflux of ammonia from bottom samples occurred in December 1999, mid to late January, and April 2000.
Total phosphate (TP) concentrations in the 0-10 cm depth and in the 10-20 cm depths of sediment in Marbellup Brook were measured in 1998 (G Bastyan pers. comm. 2000). Concentrations were variable, reflecting the accumulation of sediment in the deeper areas of the Brook. In 1998 average results were 278 mg P-PO₄/kg for the 0-10cm depths. In 1999, average P-PO₄ results were 514 mg P-PO₄/kg for the 0-5 cm depth. Concentrations of TP in the sediments are provided in Table 5.

**Figure 17. Contribution of Filterable Reactive Phosphorus (FRP) from bottom waters at sites in Marbellup Brook from November 1999 to June 2000.**

![FRP graph](image)

The FRP values from sampling sites, within the Phoslock™ treated area, ie Sites MB4, MB5, MB6 and MB7 have not been included.

**Figure 18. Contribution of averaged Filterable Reactive Phosphorus (FRP) from bottom waters at sites in Marbellup Brook from November 1999 to June 2000.**

![Averaged FRP graph](image)

Error bars = 1 standard deviation
6.2.2 Biological monitoring

In Marbellup Brook from November 1999 to May 2000, six peaks of maximum cyanobacteria cell numbers were recorded i.e. cyanobacteria cell concentrations were close to or exceeded 20,000 cells/ml. (Appendix 2, Figure 2.4). These were on 5 December, 2 January, 17 February, 12 March, 12 April and 19 April (Figure 19). In addition a chlorophyte bloom >20,000 cells/ml occurred in late December and in early April extending to June. A diatom bloom and a chlorophyte bloom (both >20,000 cells/ml) also occurred in June.

Figure 19. Average phytoplankton concentrations (cells/mL) in Marbellup Brook from November 1999 to June 2000.

In early November, diatoms (*Nitzschia*, *Skeletonema* and *Cyclotella*) dominated the phytoplankton population at all sites. At Site MB1 small counts of cyanobacteria (~100/ml) were recorded. By late November cyanobacteria (*N. spumigena*, *A. circinalis*, *Anabaenopsis* and *Pseudanabaena* sp) dominated at sites MB1 and MB2. Meanwhile, the diatoms *Skeletonema* and *Chaetoceros* sp dominated at sites MB4, MB5 and MB8.

By early December the combination of *Anabaena circinalis* and *Anabaenopsis* were present at bloom concentrations (>20,000 cells/ml) at sites MB1 and MB2 and at relatively high concentrations at sites MB5 and MB7. *Oscillatoria* sp (a filamentous benthic cyanobacteria) was also present. By late December the chlorophyte species *Ankistrodesmus*, *Cyclotella* (a diatom), and picoplankton (bacteria and minute unicellular cyanobacteria) had replaced the cyanobacteria population. Combined phytoplankton counts were >13,000,000 cells/ml. The dinoflagellate, *Protoperidinium* sp was recorded only at site MB8, in December at a concentration of 2600 cells/ml.

In early January the chlorophyte species *Ankistrodesmus* dominated sites MB1 to MB5 and at MB8. However *M. incerta* was present at MB1 in bloom proportions but had decreased at the central sites. At site MB7, *N. spumigena* had developed to a concentration of 17,000 cells/ml. By mid January the cyanobacterial bloom had collapsed although some cyanobacteria (*A. circinalis*) remained at MB1 and MB6. The diatom (*Skeletonema* sp) dominated but below bloom levels at Site MB8.

During February the concentrations of chlorophytes and cyanophytes declined to marginally below bloom levels, but during March high concentrations (> 20,000 cells/ml) of *M. incerta* at MB1 and MB7 again occurred. By mid April both *N. spumigena* and *M. incerta* reached very high concentrations (>120,000 at site MB3). These high concentrations of both
cyanobacterial species continued until late May, then by mid June had declined (though remaining above 20,000 cells/ml). Chlorophytes (Scenedesmus sp) dominated at all sites, with diatoms concentrations remaining above 20,000 cells/ml and chrysophytes averaging 1600 cells/ml throughout the Brook.

Concentrations of chlorophyll a varied at each site over time (Figure 20) and Appendix 2, Table A2.6. High chlorophyll a concentrations of up to 48 µg/L were recorded at MB6 on 20 December, MB8 on 17 January, MB4 on 4 February and MB6 again on 28 February. By 20 April high chlorophyll a concentrations (40-470 µg/L) were prevalent over most of the length of Marbellup Brook.

Figure 20. Chlorophyll a levels (µg/L) averaged from all sites in Marbellup Brook from November 1999 to June 2000.

6.2.3 Physical parameters

The average depth of the Marbellup Brook is 1.0 m with the two deepest sites being 1.3 and 1.6 m. A lower layer of saline water was present in all areas of the Marbellup Brook throughout the study period of October through to April. Anecdotal information suggested that this saline layer originated from earlier tidal propagation into the Brook. This suggestion was supported by high marine tides that occurred in late April and late May 2000, after the Torbay sand bar had been opened on 13 April. Seawater was observed to flow upstream via the Torbay Inlet and Marbellup High Level Drain to enter the penstock drain and the Marbellup Brook. The height difference between the Torbay Inlet side and the Lake Powell side of the penstocks was about 30-35 cm on the Torbay Inlet side on 26 May 2000 (G Bastyan pers. comm.). The maximum tide heights in late April and late May, as measured at the Port of Albany, occurred on 27 April and on 23 May, being 1.57 m and 1.48 m respectively. Measurements on 25 May at site MB8 showed an increase in salinity concentrations from 7.6 g/L on 26 April (the previous sampling date) to 28 ppth.

In October DO concentrations were about 7 mg/L with three sites, MB4, MB5 and MB6 continuing to have intermittent low DO concentrations of about 0.2 mg/l in December and in February. By 13 April low concentrations of DO developed at the remaining sites, MB1, MB2, MB7 and MB8 (Figure 21). Average bottom salinities had increased from 3.3 g/L to 14.6 g/L by this date. By 20 April average DO concentrations had declined to 0.1 mg/L with average bottom salinities from 14 to 16 g/L (Figure 22). After 20 April DO concentrations increased to 1.4 mg/L, by when saltwater had entered through the penstocks to increase the salinity from 9 to 28 ppth (Figure 23). In late May, sampling personnel reported the odour of
H$_2$S strong enough to postpone sampling on that day suggesting sustained low DO concentrations in bottom waters of Marbellup Brook.

Water temperatures ranged from 14.3 °C to 23.3 °C on the surface and 15.8 °C to 23.2 °C in the bottom waters. The highest temperature of 23.3 °C was recorded on 3 January (Figure 24). The entry of saltwater through the penstocks on 13 April was marked by a rapid decrease in the average temperature of surface water from 18.0 °C to 13.4 °C.

6.3 Torbay Inlet

Anecdotal reports of phytoplankton blooms have been reported in Torbay Inlet after the opening of the bar. Opening of the bar occurs when the Water Corporation lowers the water level of Lake Powell to reduce inundation on low-lying land owned by potato seed growers at Cuthbert. Cuthbert Drain takes drainage water to the Grasmere Drain. Water quality and phytoplankton data of the Torbay Inlet from October 1999 to June 2000 is provided in Appendix 3, Table A3.1. A significant bloom of *Nodularia incerta* occurred in Torbay Inlet on 26 April 2000.

6.4 Manerup Lagoon

The North Creek Drain drains wetlands and seed potato farms located at Grasmere (south of Lake Powell) to the Manerup Lagoon. Manerup Lagoon can only be drained to Torbay Inlet when the ocean sand bar is open. FRP concentrations of North Creek Drain are not available but TP concentrations were 0.02 mgP-PO$_4$/L whereas Manerup Lagoon has a TP concentration of 0.16 mg P-PO$_4$/L with an FRP concentration of 0.1 mg P-PO$_4$/L. Water quality data and phytoplankton data for the Manerup Lagoon from October 99 to June 00 is in Appendix 3, Table A3.2. Diatoms were the only phytoplankton recorded in Manerup Lagoon.

Figure 21. Concentrations of Dissolved Oxygen (mg/L) from bottom waters at sites in Marbellup Brook from November 1999 to May 2000.

The DO values from sampling sites within the Phoslock™ treated area i.e. Sites MB4, MB5, MB6 and MB7 have not been graphed.
Figure 22. Concentrations of Averaged Dissolved Oxygen concentrations (mg/L) in Marbellup Brook from November 1999 to May 2000.

Figure 23. Surface and bottom salinity levels of Marbellup Brook from November 1999 to June 2000.
Figure 24. Surface and bottom temperatures of Marbellup Brook from January to June 2000.

Error bars = 1 standard deviation

7.0 DISCUSSION

7.1. Lake Powell

The major cyanobacterial blooms of *Anabaena sp*, *Microcystis sp*, and *Nodularia sp* demonstrate that there are adequate dissolved nutrients and suitable environmental conditions such as light and temperature for rapid growth to occur. The bloom of chlorophytes, *Ankistrodesmus sp* and *Scenedesmus sp* occurred at the same time that high concentrations (1.6 – 2.7 mg/L) of N-NH₃ were recorded in Lake Powell. Certain chlorophytes are known to exhibit optimum growth in media containing high concentrations of N-NH₃ compared to N-NO₃ (Reynolds, 1984a). The main source of N-NH₃ is derived from bottom sediments as all inflows to Lake Powell have low N-NH₃ concentrations.

The low average percentage of FRP as a proportion of TP in Lake Powell was ca 11% compared to Marbellup Brook above the Plug where FRP constituted ca 51% of the TP concentration. Comparative FRP concentrations from the Five and Seven Mile Creeks to Lake Powell are not available. The Marbellup Brook catchment includes agricultural areas and soils that are similar to the Lake Powell catchment. The high levels of suspended solids in Lake Powell contrast with the low levels of suspended solids ca 5 mg/L in Marbellup Brook above the Plug. The low FRP percentage in Lake Powell may reflect the relatively high suspended solids content, FRP being adsorbed onto the suspended solids or FRP uptake by phytoplankton biomass.

Lake Powell is a very shallow water body with an average depth of 0.5 m. The dominant south and southeast winds are a major contributor to maintaining a well-mixed environment of nutrients, DO and re-suspended material. The role of wind-induced resuspension and the subsequent elevated nutrient concentrations have been reported widely. The TP concentration of Lake Arreso, Denmark was reported to increase from 0.3 to 0.8 mg/L within 9 hours as...
wind velocity increased from 4 to 10 m/sec (Sondegaard, 1992). Suspended solids increased from 50 to 190 mg/L over the same period. Based on calculations from Scheffer (1988) with a fetch of 1.8 km and wind speed of 10 km/hr the “waves” generated would extend to at least 0.5 m in depth. This corresponds to the depth of Lake Powell and hence it is likely that substantial resuspension of solids would occur maintaining elevated nutrient concentrations. The small differences between the dissolved nutrient, DO and salinity concentrations of the surface and bottom waters also suggest that wind action leads to homogenous mixing of the water body.

The water column was well mixed with salinity concentrations of between 2 and 10 ppth from December. The changing concentrations of salinity (increase in ionic strength) probably increased the flocculation of colloidal particles leading to the formation of an unstable flocculant surface sediment. The surface sediment then becomes resuspended as a result of wind action. Since 1986 the extent of variation in salinity has been reduced by the controlled entry of water through the Marbellup Plug to maintain suitable water levels in Lake Powell. Maintenance of a stable water level is required to ensure appropriate soil moisture levels in the potato growing areas of Grasmere, south of Lake Powell.

The major species of cyanobacteria occurring in Lake Powell are *N. incerta* and *A. circinalis*. Both species have the ability to produce akinetes (benthic resting forms) when conditions are unfavourable for vegetative growth to occur (Fay *et al.*, 1984). Akinetes provide a potentially significant inoculum for further cyanobacterial growth. In the Peel-Harvey Estuary of Western Australia, Huber (1984) found that the surface counts (5 cm depth) of viable akinetes of *N. spumigena* ranged from 1,400 to 95,000 akinetes/ml or $7 \times 10^5$ to $4.8 \times 10^6$ akinetes/m$^2$. Both light and temperature are considered to be prerequisites for the germination of the akinetes of *A. circinalis* (Fay *et al.*, 1984, Baker, 1990). When water temperatures exceed 20°C germination has been observed in the Murray River of Eastern Australia (Baker, 1990). Water temperatures of 20°C or more were recorded in Lake Powell from November 1999 to late February 2000. Since Lake Powell water is highly coloured, then the transport of akinetes by resuspended sediments near to the surface i.e. to the euphotic zone when high daily solar irradiation occurs, could be a crucial requirement for germination. These factors of temperature and light suggest that akinete formation by *Nodularia* and *Anabaena* species could continue to provide a substantial inoculum in future years.

The role of groundwater in the area has yet to be determined. Nutrient contributions from groundwater discharging into Wilson Inlet, an estuary 40 km west of Torbay Inlet, has been estimated at 0.2% TN and 0.5% TP (Yu, 1998) of calculated surface nutrient inputs (Lukatelich *et al.*, 1987). A similar situation may occur in Lake Powell. A positive groundwater discharge would assist in the release of soluble P-PO$_4$ and N-NH$_3$ from the sediment to the water column.

Soils of south coast of Western Australia have been surveyed to determine the nutrient availability for crop and pasture species. The Lake Powell catchment area is within this surveyed area. The soils with the highest soil bicarbonate extractable P were peats and fine textured soils such as loams and clays. These soils are likely to contribute to streamflow P, as particulate material from soil erosion, during intense rainfall over a few days (Weaver *et al.,* 1993). Because of the range of soil types and ranges of bicarbonate extractable P in these soils, and in the absence of remedial measures, there is strong likelihood that phosphorus impacts from the catchment will continue for many decades.

### 7.2 Marbellup Brook

Little or no inflow to Lake Powell was occurring during the study period. In addition, the Marbellup Plug was closed, preventing upstream water from entering the Marbellup Brook.
This suggests that the series of cyanobacterial blooms from early November to late June was sustained by the recycling of nutrients or additional benthic nutrient release.

Maximum cyanobacterial cell concentrations were recorded in December, January, February, March, April and June. The DO concentrations on sampling dates before maximum cyanobacterial cell concentrations occurred, were 0 to 1 mg/L in the bottom waters for 6 of the 8 sampling sites. Increased FRP and N-NH$_3$ concentrations occurred at the sites that exhibited the low DO concentrations. Low NOx concentrations were measured at all sampling sites suggesting that little or no nitrification (the transformation of N-NH$_3$ to NO$_3^-$) was occurring.

The cause of decreased DO (and high oxygen demand) concentrations has been ascribed to bacterial metabolism of bioavailable carbon, causing an increase in oxygen consumption and a concurrent decline in the redox potential of the sediments (Bostrom et al., 1988). When the upper layer of the sediment contains high amounts of easily degradable organic matter, high mineralisation rates can be expected (van Luijn et al., 1998). Under the reducing conditions existing, solid Fe$^{3+}$ phases are reduced to Fe$^{2+}$ and associated release of FRP occurs. Lovley et al. (1991) has shown that Fe$^{3+}$ reduction is mostly due to bacteria. Similarly, when sulphate-reducing bacteria and sufficient sulphate is present, bacteria can produce sulphide as H$_2$S. The strong smell of hydrogen sulphide noted during curtain installation for the subsequent Phoslock$^{TM}$ trial, (after 14 April 2000) and during occasional water sampling is indicative of very low DO concentrations leading to sulphate reduction.

In naturally bank vegetated streams such as Marbellup Brook, degradation of organic matter will occur as a result of riparian breakdown and oxygenation because of natural flows. Kendrick (1976) and Morrissey (1978) suggested that the source of organic material in stream sediments was from accumulated leaf material (primarily Melaluca sp) in southwestern Australia. High amounts of vegetative growth on both banks of Marbellup Brook allow absced leaves, grass and shedding bark to enter the water column. Marbellup Brook is orientated north-south for approx 1.1 km and east-west for approx 0.5 km. Since the majority of strong winds (>10km/hr) come from the south and southeast the large amount of overhanging fringing vegetation (1 to 2 m of overhang) restricts wind and wave action on the surface and subsequent mixing of the water column.

In addition to the oxic and anoxic layers of organic material, the presence of a stable lower layer of saline water in the Marbellup Brook has a dominant effect on the nutrient and phytoplankton dynamics of the water column. Increasing salinity (i.e. increasing ionic strength) is probably influential in causing flocculation and settling of particulate material during this period. At the deeper sites eg MB4 and MB5, the higher residual salinity concentrations and anoxia increases the potential contribution of soluble nutrients (N-NH$_3$ and FRP) to the water column.

Salinity concentrations increased as a result of salt-water intrusion from the opening of the sand bar at Torbay Inlet in mid April. Field observations report that water was moving upstream through the penstocks at the rate of 0.5 m/sec. (G Bastyan pers. comm. 2000). FRP concentrations increased when salt-water was observed to flow upstream through the penstocks. The increase in FRP concentrations in the bottom waters from the sediments may have been due to factors such as pore water displacement, due to the higher density seawater intruding into nutrient enriched pore waters of the unconsolidated sediments. Turbulence from the seawater intrusion may have also caused resuspension of the sediments. The presence of saline water suggests that during the numerous years when the sand bar was open, marine saline water regularly entered Marbellup Brook.

Originally, the Torbay Inlet Drainage System consisted of a series of interconnected streams and shallow storage areas that maintained an ephemeral but annual flow regime. The
construction of penstocks to control the water level of Lake Powell has prevented regular water flows through Marbellup Brook. Therefore, it is likely that particulate plant organic matter from fringing vegetation, and colloidal soil material from Lake Powell and associated catchments was retained. Most sites, and in particular sites MB1, MB4 and MB6 exhibited elevated concentrations of N-NH$_3$ and FRP depending on the level of DO present in the water column and in the presence of saline conditions. The bottom waters in the deeper sites (MB1, MB4 and MB6) were usually moderately to highly deoxygenated and had little access to oxygen inflow from surface aeration. Hence the likely source of FRP and N-NH$_3$ was from accumulated sediments at these sites. The limited or absence of water flow in summer is therefore conducive to the development of low DO conditions and the formation and release of FRP and N-NH$_3$ to the water in Marbellup Brook.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The occurrence of phytoplankton blooms in Lake Powell and Marbellup Brook are strongly influenced by nutrient release of soluble inorganic phosphate (FRP) and ammonia (N-NH$_3$) from sediments and periodic influxes of nutrients from catchment sources. In addition, physical factors such as limited circulation, low water flow, turbidity (and hence a variable light regime), temperature and the likelihood of wind-induced intermittent mixing of the water column influence phytoplankton growth.

It is recommended that a coupled nutrient flux and predictive hydrodynamic model be constructed to incorporate these to predict nutrient balance (import – internal loading including groundwater contribution– export) and phytoplankton growth. However before a predictive hydrodynamic model can be constructed, estimates of a range of parameters outlined below are required. By incorporating these parameters into a predictive hydrodynamic model for both Lake Powell and Marbellup Brook, it may then be possible to broadly assess the effects of potential remediation methods prior to implementation. Construction of a coupled nutrient flux and predictive hydrodynamic model will also allow the development of a decision framework for factors such as the maintenance of water level(s) and flow, local stakeholder input, the introduction of saline water via Torbay Inlet and the timing and extent of application of nutrient reduction strategies.

8.1 Nutrient budgets

8.1.1 Internal nutrient loadings and extent of nutrient recycling

Although the internal nutrient loadings are not known for Marbellup Brook, the relatively high nutrient levels in the bottom waters suggest a significant contribution of derived nutrients from bottom sediments. Because of the orientation of Marbellup Brook, the combination of low water flow and low mean wind speed can lead to the development of persistent thermal stratification (Bormans, et al (1997). Estimates of internal nutrient loadings and extent of nutrient recycling will also be required for Lake Powell. Preliminary assessment with sediment cores and with selected use of in-situ benthic chambers is recommended to determine the extent of nutrient recycling and nutrient release from sediments.

8.1.2 External nutrient loadings

Broad-scale estimates of external nutrient loadings can be estimated on an annual basis. However, these loadings are based on infrequent (fortnightly or greater) water sampling, estimated and median flow rates. Refined estimates over a range of flow conditions are required since nutrient inputs could be related to seasonal agricultural activities and/or rainfall frequency. Identification of key external nutrient inputs are also required.
8.1.3 Nutrient export

The extent of nutrient export from both Lake Powell and Marbellup Brook is not known. Estimates of nutrient removal through the penstocks to the Marbellup High Level Drain are required. Periodic releases of water are required to maintain a suitable level between the Critical Level (CL) and the Maintenance Base Level (MBL) of Lake Powell and Marbellup Brook. Currently, water can leak through the penstocks from Marbellup Brook via the penstocks drain.

8.1.4 Influence of zooplankton

Predation of phytoplankton and the extent of nutrient recycling as a consequence of *Daphnia* grazing are not known. Field staff reported a large population of *Daphnia* in late February 2000 in Lake Powell having an observable effect on phytoplankton concentrations (G Bastyan *pers comm.* February 2000). Zooplankton can feed partly or wholly on phytoplankton and bacteria and can influence species’ composition and phytoplankton succession (Reynolds, 1984b). At the same time they can release nutrients, which may contribute to phytoplankton growth. Reports on zooplankton indicate that Australian native zooplankton cannot consume cyanobacteria at rates required to control phytoplankton blooms (Boon, *et al* 1994).

8.1.5 Nutrient bioassays

Nutrient bioassay measurements could be undertaken to establish the effects and occurrence of nitrogen and phosphate limitation on phytoplankton growth in both Lake Powell and Marbellup Brook. The results of these nutrient bioassays could be considered as a basis for the trial of a particular nutrient-reduction strategy and to gauge its effectiveness.

8.2 Physical factors

8.2.1 Salinity

The effects of salinity on phytoplankton biomass and/or species composition and that of other biota in Lake Powell/Torbay Inlet /Marbellup Brook system are not known. The effect of saline stratification and density displacement of pore water has the potential to significantly augment nutrient flux from the bottom sediments into the overlying water column. In addition, the presence of saline water as part of the periodic inflows from Torbay Inlet may also influence phytoplankton species and succession and grazer (*eg Daphnia spp*) populations.

8.2.2 Mixing, stratification and hydraulic retention

Highly variable wind conditions (wind speed of 10 km/hr is exceeded 69% of the time from all directions from November to May, while wind speed of <1km/hr occur at a frequency of 16% annually) occur in Lake Powell. This variability suggests that there may be periods of both pronounced mixing (a wind speed of >ca. 30km/hr would produce a standing wave capable of mixing the water column in Lake Powell) leading to sediment resuspension and mixing of nutrient-enriched bottom waters, while quiescent conditions would promote the development of significant thermal stratification and/or maintenance of salinity stratification when present. In contrast, because of the orientation of Marbellup Brook, the combination of static or low water flow and decreased influence to wind due to tall overhanging vegetation, thermally stratified conditions are likely to be maintained for greater period than in Lake Powell. A generalised relationship between irradiation and wind speed could be used to predict mixing conditions at different times of the year (Bormans, 1977) for both Marbellup Brook and Lake Powell.
Estimates of the hydraulic retention time for both Lake Powell and Marbellup Brook are also required. The hydraulic retention time is a measure of the average residence time of water within a lake and has been used to predict the effects of reduction in nutrient loadings in lakes (Schaffer 1998). In the context of Lake Powell estimates of hydraulic retention time would be an essential parameter to predict and model the effectiveness of modification of flow into and out of Lake Powell as discussed in Section 9.

8.2.3 Light limitation

Light limitation within the water body can affect phytoplankton growth. Sherman et al (1994) and Webster et al (1997) have reported on large variations in phytoplankton biomass occurring as a result of changing light conditions. Cyanobacteria can through buoyancy regulation, position themselves in the water column to maximize their light uptake relative to other phytoplankton species, allowing a competitive advantage to certain species. To determine the significance of light to affect phytoplankton growth rate, light regimes and their link to biomass and species need to be measured in both water bodies and linked to the coupled nutrient and predictive hydrodynamic model.

9.0 POTENTIAL MANAGEMENT AND REMEDIATION MEASURES

Potential remediation methods are briefly discussed below. These potential methods may have to be reviewed in light of outcomes from a coupled nutrient flux and predictive hydrodynamic model.

9.1 Modification of flow regime

Increased flows (periodic flushing) under appropriate conditions have the potential to reduce phytoplankton growth by reducing (via maintenance of more oxidizing conditions) diluting and partially exporting the internal sediment nutrient load, increasing turbidity (to reduce light) and maintaining a changing water environment so that rates of phytoplankton growth are kept low. Cyanobacterial dominance has not been observed in lakes where the hydraulic retention time is less than five days (Scheffer, 1998).

9.1.1 Linking Lake Powell with North Creek Drain

By linking Lake Powell to the North Creek Drain, water from Grasmere Drain would pass through Lake Powell to the North Creek Drain and onto Torbay Inlet via the Manerup Lagoon to improve mixing and flushing. This re-routing of water could only occur when the ocean sand bar has been breached and low marine tides occur. Only limited mixing and flushing in Lake Powell could result because of the exit drain would be relatively close i.e. 1 km from the Grasmere Drain entry point, reducing the possibility of loss of nutrients and phytoplankton biomass. As well, the capacity of the siphon, under the Marbellup High Level Drain may limit water flow. Because the North Creek Drain is linked to the Manerup Lagoon, there is also the possibility of phytoplankton contaminated water entering the Lagoon. The environmental conditions for phytoplankton growth in Manerup Lagoon can be regarded as being very favourable i.e. adequate nutrients and shallow depth (0.4 m). Thus, the possibility of creating further phytoplankton blooms in Manerup Lagoon is high. A benefit to local seed potato farmers at Grasmere is that the control of sub-soil moisture could be improved before planting.

9.1.2 Removing the Marbellup Plug and linking Lake Powell to North Creek Drain

Removal of the Marbellup Plug has been proposed to increase water flow through Lake Powell to the North Creek Drain and to the Maranup Lagoon. This modification would reduce
the hydraulic retention time of water in both Lake Powell and Marbellup Brook. Increased flow would occur when the level of Lake Powell was lower than Marbellup Brook at Elleker, allowing Marbellup Brook to be flushed to the North Creek Drain. Control gates or penstocks would be required at the Marbellup Brook/Lake Powell entrance but would allow improved control of water levels and flows. Benefits would be a possible reduction in hydraulic residence time leading to a reduction in phytoplankton concentrations. The possibility of creating further phytoplankton blooms in Manerup Lagoon is high as discussed in Section 9.1.1.

9.1.3 Amalgamation of High Level and Mid Level drainage systems

Construction of levee banks have been proposed around Lake Powell (Anonymous, 1995) so that the high water level system (Marbellup Brook/Torbay Inlet) can be synchronised with the mid water level system (Grassmere Drain/Lake Powell). Both systems would operate at a common water level and would simplify operational requirements. However, water flow in the Marbellup Brook below the “Plug” after levee construction may not be significantly greater than that allowed by the current “Plug” and requires further investigation. Benefits would be the maintenance of a water level higher than current practice in Lake Powell (as desired by Grasmere seed potato farmers), removal of the “Plug” in Marbellup Brook, and removal of penstocks at Bridge 45. Part of this management option would be similar to that operating before the Marbellup High Level Drain was constructed.

9.1.4 Re-design of Marbellup Brook

Various locations in the Marbellup Brook are lower than the position of the pipe within the earthen bank i.e. the “Marbellup Plug”. Relatively high concentrations of soluble phosphate are released at the depressions that are subject to periodic anoxia within the Brook. Therefore, a remedial solution is to infill the Brook to remove deep depressions. A benefit is that the amount of soluble phosphate may be reduced, but the extent of the reduction in derived nutrients may be insufficient to reduce excessive phytoplankton growth.

9.1.5 Management of the sand bar

The timing of the breaking of the sand bar affects the water levels and drainage characteristics of the entire drainage system. The intermittent closure of the sand bar prevents the Water Corporation from being able to maintain adequate flows to reduce phytoplankton bloom problems. To meet the requirement that low-lying agricultural land in the Cuthbert and North Creek areas does not remain inundated for more than 72 hours, the WA Water Corporation has to ensure that sufficient volumetric capacity is maintained within the drainage system. When the volumetric capacity is close to being exceeded, the sand bar has to be opened manually. The dark coloured water may then affect the local salmon fishing industry.

The gradual or slow release of dark coloured water from Torbay Inlet using a submerged pipe and/or manifold (so that dilution could take place) may alleviate the dark-coloured water problem. A permanently opened sand bar would assist the Water Corporation to increase flows to remove occasional large quantities of drainage water.

Particular caution must, however, be exercised when opening the sandbar for extended periods and in particular in the presence of high tides. Uncontrolled influx of seawater may lead to adverse accumulations of saline water, undesirable changes in biota and intrusion/displacement of local shallow groundwater. Thus, it is probable that the introduction of seawater could only be used as a short-term measure to partially flush Torbay Inlet and/or Lake Powell and prevent the growth of salt-sensitive phytoplankton species.
9.2 Nutrient stabilisation

The aim of nutrient stabilisation is to reduce the nutrient content in the water column and the release of nutrients from bottom sediments. If nutrient release can be sufficiently reduced, then the most limiting nutrient limits the growth of many phytoplankton except in the case of nitrogen where under appropriate conditions, nitrogen-fixing cyanobacteria may predominate.

9.2.1 Alum treatment

Alum (aluminium sulphate) has been added to lake water to form a colloidal aluminium hydroxide floc. Dissolved and particulate phosphate fractions then become bound within the floc. The aluminium hydroxide floc settles onto the sediment and continues to sorb and retain phosphate (Cooke et al., 1986). However it is unlikely that the use of this method in natural waters will gain regulatory approval because of the potential of aluminium toxicity.

9.2.2 Phoslock™ treatment

The use of a modified clay (Phoslock™) developed by CSIRO and the Water and Rivers Commission offers another form of phosphate stabilisation and reduction. The modified clay can be applied as a slurry over the surface of the lake and allowed to settle. The soluble phosphate in the water column and the soluble phosphate (FRP) released from the sediment is retained by the modified clay under a wide range of environmental conditions.

9.2.3 Sediment oxidation

Sediment oxidation has been trialled as a method to control internal phosphate loadings from anaerobic sediments. Usually this involves calcium nitrate, Ca(NO₃)₂, being injected into the top 20 cm of lake sediments to stimulate loss of nitrogen by oxidation and ultimately denitrification. Potential benefits include degradation of organic matter, oxidation of iron compounds and inactivation of phosphorus by sorption to the oxidised iron (Ripl, 1994). Potential problems in the use of calcium nitrate may occur if not all of the nitrate is consumed after injection or is rejected from the sediment into the water column by groundwater flow. Excess nitrate may (if phytoplankton are nitrogen limited), potentially lead to an increase in phytoplankton biomass.

9.3 Artificial destratification

It is likely that the presence of a persistent saline lower layer over the summer period in the Marbellup Brook and/or Lake Powell, leads to the production of significant concentrations of phosphate and ammonia. Artificial destratification of the water column would lead to higher bottom water dissolved oxygen concentrations, a likely consequent reduction of nutrient release and an improvement of habitat for biota. Destratification is usually accomplished by bottom-mounted bubblers or mechanical mixers.

9.4 Catchment management

The cumulative effect of land clearing and fertilisation appears to have lead to nutrient-enriched sediments in Lake Powell and Marbellup Brook and many minor tributaries. As an example, data from the Oyster Harbour catchment, the catchment adjacent to the Torbay Inlet catchment demonstrated that 56% of that catchment contains P in excess of plant requirements (Weaver et al., 1988). However, it is thought that the decline in soluble phosphate concentrations is likely to be noticeable only over decades. Thus, urgent and intensive efforts are required to address the input of catchment nutrients over the next years to decades. Efforts are currently in progress to introduce protection or rehabilitation of vegetation along both major and minor streamlines along the Five Mile and Seven Mile...
creeks in the Torbay Inlet Catchment to reduce nutrient loss from farmland (Green Skills, 2000). Extension of these efforts to other key tributaries are recommended in the context of long-term management strategy.

9.5 Biomanipulation

A relatively new method of phytoplankton control in Australia is by biomanipulation. Selected fish species at predetermined numbers consume the zooplankton and phytoplankton as a food source. A CSIRO trial is underway in two reservoirs in Queensland to confirm the suitability of the concept for phytoplankton control (Matveev, 1998). Biomanipulation may, however, only have a limited application and impact due to the partially (seasonally) open system behaviour of the Torbay Inlet/Marbellup Brook/Lake Powell system.

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11.0 REFERENCES


South Coast Regional Land and Water Care Strategy 1995/96 (1996). The Albany Hinterland Sub-Region. *The South Coast Regional Assessment Panel and South Coast Regional Initiative Planning Team*.


APPENDIX 1 : Lake Powell
Figure A1.1: Depths (m), Salinity (ppth) and pH of Lake Powell from 1981 to 1997

Data supplied by Department of Conservation and Land Management
Figure A1.2: Phytoplankton in Lake Powell from October 1999 to June 2000

Top graph (Y axis) = linear scale
Lower graph (Y axis) = log scale
Figure A1.3: Cyanobacteria levels in Lake Powell from October 1999 to June 2000

- Top graph (Y axis) = linear scale
- Lower graph (Y axis) = log scale
- Cell counts (cells/ml) are provided at the top of each bar
## Table A1.1.1: Physico-chemical and nutrient data for Lake Powell from October 1999 to June 2000

|     | TP (mg/L) | 7-Oct | 2-Nov | 23-Nov | 6-Dec | 20-Dec | 3-Jan | 17-Jan | 4-Feb | 18-Feb | 28-Feb | 13-Mar | 27-Mar | 13-Apr | 27-Apr | 27-May | 23-Jun |
|-----|-----------|-------|-------|--------|-------|--------|-------|-------|-------|-------|--------|--------|--------|--------|--------|--------|--------|-------|
| 1LP | Sfce     | 0.19  | 0.65  | 0.32   | 0.22  | 0.31   | 0.63  | 0.78  | 0.31  | 0.43  | 0.40   | 0.30   | 0.74   | 0.84   | 0.70   | 0.45   | 0.22  |
| 1LP | Btm      | na    | 0.65  | 0.32   | 0.18  | 0.31   | 0.65  | 0.78  | 0.34  | 0.43  | 0.40   | 0.31   | 0.74   | 0.84   | 0.77   | 0.45   | 0.24  |
| 1LP | Sfce     | na    | 0.93  | 0.27   | 0.13  | 0.33   | 0.82  | 0.38  | 0.26  | 0.43  | 0.43   | 0.31   | 0.58   | 0.635  | 0.57   | 0.44   | 0.26  |
| 1LP | Btm      | 0.16  | 1.10  | 0.26   | 0.13  | 0.27   | 0.87  | 0.33  | 0.26  | 0.28  | 0.39   | 0.31   | 0.58   | 0.635  | 0.59   | 0.46   | 0.26  |
| 1LP | Btm      | 0.19  | 0.61  | 0.72   | 0.15  | 0.88   | 1.10  | 0.87  | 0.31  | 0.595 | 0.74   | 0.24   | 0.55   | 0.56   | 0.55   | 0.52   | 0.27  |

|     | FRP (mg/L) | 7-Oct | 2-Nov | 23-Nov | 6-Dec | 20-Dec | 3-Jan | 17-Jan | 4-Feb | 18-Feb | 28-Feb | 13-Mar | 27-Mar | 13-Apr | 27-Apr | 27-May | 23-Jun |
|-----|------------|-------|-------|--------|-------|--------|-------|-------|-------|-------|--------|--------|--------|--------|--------|--------|--------|-------|
| 1LP | Sfce      | 0.096 | 0.10  | 0.017  | 0.044 | 0.008  | 0.012 | 0.060 | 0.038 | 0.073 | 0.058  | 0.083  | 0.05   | 0.043  | 0.047  | 0.01   | 0.018 |
| 1LP | Btm       | na    | 0.10  | 0.017  | 0.037 | 0.008  | 0.019 | 0.060 | 0.052 | 0.073 | 0.063  | 0.083  | 0.050  | 0.043  | 0.053  | 0.01   | 0.016 |
| 1LP | Sfce      | 0.088 | 0.098 | 0.015  | 0.013 | 0.013  | 0.018 | 0.080 | 0.045 | 0.074 | 0.063  | 0.068  | 0.045  | 0.050  | 0.045  | 0.008  | 0.019 |
| 1LP | Btm       | na    | 0.110 | 0.015  | 0.011 | 0.010  | 0.019 | 0.080 | 0.052 | 0.074 | 0.063  | 0.074  | 0.045  | 0.050  | 0.045  | 0.01   | 0.020 |
| 1LP | Btm       | 0.064 | 0.093 | 0.019  | 0.020 | 0.012  | 0.015 | 0.080 | 0.040 | 0.068 | 0.058  | 0.051  | 0.038  | 0.042  | 0.040  | 0.007  | 0.019 |
| 1LP | Btm       | 0.094 | 0.019 | 0.019  | 0.012 | 0.015  | 0.080 | 0.049 | 0.068 | 0.059 | 0.050  | 0.038  | 0.042  | 0.036  | 0.007  | 0.020  |       |

|     | N-NH3 (mg/L) | 7-Oct | 2-Nov | 23-Nov | 6-Dec | 20-Dec | 3-Jan | 17-Jan | 4-Feb | 18-Feb | 28-Feb | 13-Mar | 27-Mar | 13-Apr | 27-Apr | 27-May | 23-Jun |
|-----|--------------|-------|-------|--------|-------|--------|-------|-------|-------|-------|--------|--------|--------|--------|--------|--------|--------|-------|
| 1LP | Sfce        | 0.026 | 0.040 | 0.031  | 0.014 | 0.078  | 0.028 | 1.60  | 2.50  | 2.80  | 0.030  | 0.073  | 0.092  | 0.060  | 0.074  | 0.072  | 0.05  |
| 1LP | Btm         | na    | 0.040 | 0.031  | 0.011 | 0.078  | 0.027 | 1.60  | 2.50  | 2.80  | 0.028  | 0.079  | 0.092  | 0.060  | 0.110  | 0.030  | 0.05  |
| 1LP | Sfce        | 24    | 0.038 | 0.031  | 0.042 | 0.027  | 0.018 | 1.60  | 2.70  | 2.50  | 0.036  | 0.024  | 0.048  | 0.083  | 0.051  | 0.058  | 0.05  |
| 1LP | Btm         | na    | 0.041 | 0.031  | 0.033 | 0.032  | 0.014 | 1.60  | 2.70  | 2.50  | 0.028  | 0.029  | 0.048  | 0.083  | 0.046  | 0.069  | 0.05  |
| 1LP | Sfce        | 0.021 | 0.073 | 0.031  | 0.030 | 0.020  | 0.014 | 1.60  | 2.80  | 2.40  | 0.025  | 0.024  | 0.056  | 0.040  | 0.048  | 0.041  | 0.05  |
| 1LP | Btm         | na    | 0.071 | 0.031  | 0.034 | 0.020  | 0.014 | 1.60  | 2.700 | 2.40  | 0.039  | 0.030  | 0.056  | 0.040  | 0.064  | 0.043  | 0.05  |
Table A1.1.2 : Physico-chemical and nutrient data for Lake Powell from October 1999 to June 2000

| TN (mg/L) | 7-Oct | 2-Nov | 23-Nov | 6-Dec | 20-Dec | 3-Jan | 17-Jan | 4-Feb | 18-Feb | 28-Feb | 13-Mar | 27-Mar | 13-Apr | 27-Apr | 27-May | 23-Jun |
|-----------|-------|-------|--------|-------|--------|-------|--------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| LP1 Sfce  | 0.0   | 2.6   | 2.1    | 1.8   | 2.5    | 3.8   | 5.7    | 4.6   | 2.5    | 3.6    | 2.4    | 5.5    | 5.7    | 5.4    | 3.8    | 1.9    |
| LP1 Btm   | 2.0   | 2.6   | 2.1    | 1.8   | 2.5    | 3.6   | 5.7    | 4.7   | 2.5    | 3.7    | 2.4    | 5.5    | 5.7    | 5.6    | 3.7    | 2.0    |
| LP2 Sfce  | 0.0   | 3.7   | 2.3    | 1.8   | 2.1    | 4.3   | 3.9    | 4.8   | 2.3    | 3.9    | 2.5    | 5.2    | 5.5    | 5.1    | 3.7    | 2.1    |
| LP2 Btm   | 1.7   | 4.2   | 2.3    | 1.7   | 2.3    | 4.5   | 3.9    | 4.7   | 2.3    | 3.6    | 2.7    | 5.2    | 5.5    | 5.2    | 3.7    | 2.1    |
| LP3 Sfce  | 0.0   | 2.5   | 3.2    | 1.8   | 4.1    | 5.4   | 6.3    | 5.0   | 3.7    | 4.7    | 2.7    | 5.2    | 5.2    | 5.1    | 4.1    | 2.2    |
| LP3 Btm   | 1.8   | 2.7   | 3.2    | 1.7   | 4.1    | 5.4   | 6.3    | 5.0   | 3.7    | 4.9    | 2.5    | 5.2    | 5.2    | 5.1    | 4.1    | 2.3    |

| NOx (mg/L) | 7-Oct | 2-Nov | 23-Nov | 6-Dec | 20-Dec | 3-Jan | 17-Jan | 4-Feb | 18-Feb | 28-Feb | 13-Mar | 27-Mar | 13-Apr | 27-Apr | 27-May | 23-Jun |
|------------|-------|-------|--------|-------|--------|-------|--------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| LP1 Sfce   | na    | 0.005 | 0.005  | 0.005 | 0.005  | 0.054 | 0.39   | 0.005 | 0.017  | 0.005  | 0.005  | 0.05  | 0.005  | 0.005  | 0.005  | 0.005  |
| LP1 Btm    | na    | 0.005 | 0.005  | 0.005 | 0.005  | 0.054 | 0.42   | 0.005 | 0.013  | 0.005  | 0.005  | 0.05  | 0.005  | 0.005  | 0.005  | 0.005  |
| LP2 Sfce   | na    | 0.005 | 0.005  | 0.005 | 0.005  | 0.049 | 0.44   | 0.005 | 0.005  | 0.005  | 0.005  | 0.05  | 0.005  | 0.005  | 0.005  | 0.005  |
| LP2 Btm    | na    | 0.005 | 0.005  | 0.005 | 0.005  | 0.049 | 0.43   | 0.005 | 0.005  | 0.005  | 0.005  | 0.05  | 0.005  | 0.005  | 0.005  | 0.005  |
| LP3 Sfce   | na    | 0.005 | 0.005  | 0.005 | 0.005  | 0.053 | 0.43   | 0.005 | 0.005  | 0.005  | 0.005  | 0.05  | 0.005  | 0.005  | 0.005  | 0.005  |
| LP3 Btm    | na    | 0.005 | 0.005  | 0.005 | 0.005  | 0.053 | 0.41   | 0.005 | 0.013  | 0.005  | 0.005  | 0.05  | 0.005  | 0.005  | 0.005  | 0.005  |

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Table A1.1.3 : Physico-chemical and nutrient data for Lake Powell from October 1999 to June 2000

| DO (mg/L)    | 7-Oct | 2-Nov | 23-Nov | 6-Dec | 20-Dec | 3-Jan | 17-Jan | 4-Feb | 18-Feb | 28-Feb | 13-Mar | 27-Mar | 13-Apr | 27-Apr | 27-May | 23-Jun |
|-------------|-------|-------|--------|-------|--------|-------|--------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| **LP1 Sfce** | 7.8   | 9.3   | 9.7    | 5.6   | 9.3    | 9.5   | 7.1    | 6.8   | 7.5    | 6.4    | 8.6    | 6.5    | 11.1   | 7.3    | 7.7    | 7.8    |
| **LP1 Btm**  | 7.7   | 9.3   | 10.0   | 5.6   | 9.1    | 9.0   | 7.0    | 6.6   | 7.5    | 6.3    | 8.4    | 6.2    | 11.0   | 7.2    | 7.7    | 8.0    |
| **LP2 Sfce** | 8.5   | 9.0   | 10.0   | 8.6   | 9.8    | 9.5   | 7.4    | 7.1   | 7.2    | 7.9    | 9.0    | 9.5    | 11.4   | 7.8    | 8.5    | 8.2    |
| **LP2 Btm**  | 8.5   | 9.0   | 10.2   | 8.6   | 9.2    | 9.7   | 7.4    | 7.1   | 7.2    | 7.7    | 8.8    | 9.5    | 11.8   | 7.8    | 8.5    | 8.5    |
| **LP3 Sfce** | 7.8   | 9.0   | 9.6    | 8.3   | 8.6    | 8.6   | 7.0    | 7.2   | 7.2    | 6.6    | 9.7    | 9.5    | 11.2   | 7.2    | 8.4    | 8.1    |
| **LP3 Btm**  | 7.9   | 9.0   | 9.7    | 8.0   | 8.4    | 8.6   | 6.8    | 7.0   | 7.1    | 6.2    | 9.7    | 9.1    | 11.2   | 7.1    | 8.4    | 8.5    |

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<th>23-Nov</th>
<th>6-Dec</th>
<th>20-Dec</th>
<th>3-Jan</th>
<th>17-Jan</th>
<th>4-Feb</th>
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<th>23-Nov</th>
<th>6-Dec</th>
<th>20-Dec</th>
<th>3-Jan</th>
<th>17-Jan</th>
<th>4-Feb</th>
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APPENDIX 2 : Marbellup Brook
Figure A2.1: Average Total Nitrogen (TN) (mg/L) and as Average N-NH$_3$ (mg/L) in Marbellup Brook above the Plug from 1987 to 1997.

TN data is from Jul 1988 to May 1990 and Dec 1991 to Apr 1997

N-NH$_3$ data is from December 1987 to April 1997

Data from Water and Rivers Commission
Figure A2.2: Total Phosphorus (TP) and Filterable Reactive Phosphorus (FRP) measured as P-PO₄ (mg/L) in Marbellup Brook above the Plug from 1987 to 1997.

TP was measured from December 1987 to July 1990
FRP was measured from May 1991 to April 1997
Data supplied by Water and Rivers Commission

Figure A2.3: Chloride (Cl) values from Marbellup Brook above the Plug from 1971 to 1998.

Chloride values were measured from October 1971 to October 1998
Figure A2.4.1: Marbellup Brook phytoplankton counts (cells/ml) by sampling site

2 Nov 99

22 Nov 99

5 Dec 99
Figure A2.4.2: Marbellup Brook phytoplankton counts (cells/ml) by sampling site

19 Dec 99

2 Jan 00

3 Feb 00
Figure A2.4.3: Marbellup Brook phytoplankton counts (cells/ml) by sampling site.

4 Feb 00

18 Feb 00

28 Feb 00

MB1 MB2 MB3 MB4 MB5 MB6 MB7 MB8

Diatoms
Dinophyta
Cyanophyta
Chlorophyta
Cryptophyta
Euglenophyta
Chrysophyta
Others
Pico/Ultra

MB1 MB2 MB3 MB4 MB5 MB6 MB7 MB8

Diatoms
Dinophyta
Cyanophyta
Chlorophyta
Cryptophyta
Euglenophyta
Chrysophyta
Others
Pico/Ultra

MB1 MB2 MB3 MB4 MB5 MB6 MB7 MB8

Diatoms
Dinophyta
Cyanophyta
Chlorophyta
Cryptophyta
Euglenophyta
Chrysophyta
Others
Pico/Ultra

MB1 MB2 MB3 MB4 MB5 MB6 MB7 MB8

Diatoms
Dinophyta
Cyanophyta
Chlorophyta
Cryptophyta
Euglenophyta
Chrysophyta
Others
Pico/Ultra
Figure A2.4.4: Marbellup Brook phytoplankton counts (cells/ml) by sampling site
Figure A2.4.5: Marbellup Brook phytoplankton counts (cells/ml) by sampling site

Sampling on 15th April was completed only at Sites MB1, MB4 and MB8

Sampling on 19th April was completed only at Sites MB1, MB3, MB4 and MB8

Sampling on 27th April was completed at all Sites MB1 to MB8.
Figure A2.4.6: Marbellup Brook phytoplankton counts (cells/ml) by sampling site

25 May 2000

23 Jun 00
Table A.2.1: Marbellup Plug opening and closing dates from 1996 to 2000

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<td>19 May 00</td>
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Information supplied by D. Wright, Operations Manager, Water Corporation, Albany
Table A2.2.1: Nutrient data and physico-chemical data for Marbellup Brook from October 1999 to June 2000

Total Phosphorus (TP) Shaded area = concentrations at sites within the Phoslock™ trial area
(mgP-PO₄/L)  S = Surface sample  B = Bottom sample

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<td>B</td>
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<tr>
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Table A2.2.2: Nutrient data and physico-chemical data for Marbellup Brook from October 1999 to June 2000

FRP  Shaded area = concentrations at sites within the Phoslock™ trial area
      (mg P-PO₄/L)  S = Surface sample  B = Bottom sample

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Table A2.2.3: Nutrient data and physico-chemical data for Marbellup Brook for Marbellup Brook from October 1999 to June 2000

N-NH$_3$  Shaded area = concentrations at sites within the Phoslock™ trial area
(mg/L)     S = Surface sample B = Bottom sample

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Table A2.2.4: Nutrient data and physico-chemical data for Marbellup Brook for Marbellup Brook from October 1999 to June 2000

N-NOx Shaded area = concentrations at sites within the Phoslock™ trial area
S = Surface sample B = Bottom sample
Table A2.2.5: Nutrient data and physico-chemical data for Marbellup Brook for Marbellup Brook from October 1999 to June 2000

TN Shaded area = concentrations at sites within the Phoslock™ trial area  
(mg/L) S = Surface sample  B = Bottom sample

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Table A2.2.6: Nutrient data and physico-chemical data for Marbellup Brook from October 1999 to June 2000

Dissolved oxygen (DO)  Shaded area = concentrations at sites within the Phoslock™ trial area  (mg/L)

S = Surface sample  B = Bottom sample

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Table A2.2.7 : Nutrient data and physico-chemical data for Marbellup Brook for Marbellup Brook from October 1999 to June 2000

Dissolved Oxygen (%)  Shaded area = concentrations at sites within the Phoslock™ trial area  S = Surface sample  B = Bottom sample

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Table A2.2.8: Nutrient and physico-chemical data for Marbellup Brook from October 1999 to June 2000

Specific Conductivity  Shaded area = concentrations at sites within the Phoslock™ trial area  (mS/cm)  S = Surface sample  B = Bottom sample

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Table A2.2.9: Nutrient data and physico-chemical data for Marbellup Brook for Marbellup Brook from October 1999 to June 2000

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Table A2.2.10 : Nutrient data and physico-chemical data for Marbellup Brook

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**Notes:**
- **Diatoms:** Diatoms (Nitzchia, Skeletonema, Cyanobacteria)
- **Dinophyta:** Dinoflagellates
- **Cyanophyta:** Cyanobacteria
- **Chlorophyta:** Chlorophytes
- **Crypto phyta:** Cryptophytes
- **Eugleno phyta:** Euglenophytes
- **Chrysophyta:** Chrysophytes
- **Others:** Other phytoplankton species
- **TOTAL:** Total phytoplankton concentration
- **Pico-Ultra:** Pico- and Ultra-nanoplankton
- **MAJOR SPECIES:** Major species

**Major Species:**
- Nitzchia
- Skeletonema
- Mix Chlorophyta
- Protoperidinium sp
- Mix Cyanobacteria
- Mix Cyanobacteria

**References:**
- Table A2.3.1 provides data on phytoplankton concentrations (cells/mL) in Marbellup Brook from November 1999 to June 2000.

**Analysis:**
- The data shows a diversity of phytoplankton species, with Nitzchia and Skeletonema being the major species in different samples.
- The concentrations vary significantly across different samples and dates, indicating dynamic changes in the phytoplankton community over time.
- The study highlights the importance of monitoring phytoplankton concentrations for understanding aquatic ecosystem health and function.
Table A2.3.2: Phytoplankton concentrations (cells/mL) in Marbellup Brook from November 1999 to June 2000

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76
Table A2.3.3: Phytoplankton concentrations (cells/mL) in Marbellup Brook from November 1999 to June 2000

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Table A2.3.4: Phytoplankton concentrations (cells/mL) in Marbellup Brook from November 1999 to June 2000

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<th>MB3</th>
<th>MB4</th>
<th>MB5</th>
<th>MB6</th>
<th>MB7</th>
<th>MB8</th>
<th>TOTAL</th>
<th>MAJOR SPECIES</th>
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Note: The dates are abbreviated as 'Apr-00', 'Apr-00', 'Apr-00', and 'Apr-00' respectively.
Table A2.3.5: Phytoplankton concentrations (cells/mL) in Marbellup Brook from November 1999 to June 2000

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<td>Crypto</td>
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Data supplied by Phytoplankton Ecology Unit, Water and Rivers Commission
APPENDIX 3 : Manerup Lagoon, Torbay Inlet and Cuthbert Drain
## Table A3.1: Water quality data - North Creek Drain and Cuthbert Drain

### North Creek Drain on 24 Sep 1998

<table>
<thead>
<tr>
<th>Location</th>
<th>TP (mg/L)</th>
<th>TN (mg/L)</th>
<th>Turbidity (NTU)</th>
<th>Flow Rate (m³/sec)</th>
<th>DO (mg/L)</th>
<th>Temp °C</th>
<th>ECon d (µS/cm)</th>
<th>pH</th>
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### Cuthbert Drain on 24 Sep 1998

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<th>TP (mg/L)</th>
<th>TN range (mg/L)</th>
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Data from Water and Rivers Commission, Albany
Table A3.2: Nutrient concentrations of Maranup Lagoon

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<th></th>
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<th>SpCond (mS/cm)</th>
<th>Sal (g/L)</th>
<th>DO (mg/L)</th>
<th>TP (mg/L)</th>
<th>FRP (mg/L)</th>
<th>N-NH3 (mg/L)</th>
<th>TON (mg/L)</th>
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After 17 Jan 00 the water level (~ 10-15 cm) was too low to allow access for sampling

**Phytoplankton recorded from Maranup Lagoon on 20 Dec 1999**

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### Table A3.3: Nutrient and phytoplankton concentrations of Torbay Inlet

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<th>SpCond (mS/cm)</th>
<th>Salin (ppt)</th>
<th>DO (mg/L)</th>
<th>pH</th>
<th>DO (% sat)</th>
<th>TP (mg/L)</th>
<th>FRP (mg/L)</th>
<th>N-NH₄ (mg/L)</th>
<th>TON⁽¹⁾ (mg/L)</th>
<th>TN (mg/L)</th>
<th>Chl a (µg/L)</th>
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Data from 1988 to 1997 supplied by Water and Rivers Commission, Albany.

Nutrient concentrations not supplied for 23 June 2000

1. TON = Total Organic Nitrogen

2. WRC, Lake Powell/ Torbay Inlet Catchment Snapshot Water Quality Survey, 24 April 1998

### Phytoplankton levels in Torbay Inlet from August 1999 to May 2000

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<tr>
<th>Date</th>
<th>Diatoms</th>
<th>Dino phyta</th>
<th>Cyanophyta</th>
<th>Chlor o phyta</th>
<th>Crypt o phyta</th>
<th>Eugle nophyta</th>
<th>Chry sop hyta</th>
<th>TOT AL</th>
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<tr>
<td>4 Aug-99</td>
<td>68</td>
<td>1,772</td>
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<td>1,444</td>
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