SOUTHERN GRAMPIANS SHIRE COUNCIL

ACTION PLAN FOR THE IMPROVEMENT OF WATER QUALITY

LAKE HAMILTON

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Executive Summary

Lake Hamilton is located in the Victorian western district town of Hamilton and is fed by the Grange Burn, urban stormwater and overland flow. The Lake is a popular recreational area and has a high environmental, social and economic value to Hamilton and the regional community. Recurring high levels of Cyanobacteria and *E. coli* have activated the Southern Grampians Shire Council's management process resulting in warning signs being erected to deter the use of the Lake due to potential public health issues.

Lake Hamilton has been undergoing a long period of eutrophication. A review of the monitoring program and available literature found that the main factor contributing to the Cyanobacterial blooms was excessive nutrients entering the Lake from stormwater drains and the Grange Burn. There is also a large bank of nutrients contained within the Lake sediments.

Short to medium-term remedial control options that have the potential to treat the Cyanobacterial blooms include the use of chemicals (as algicides), microorganisms to consume nutrients, or dyes to attenuate sunlight and thereby discouraging algal growth. However, the use of these short-term options may pose risks to the Lake ecosystem and further downstream in the Grange Burn. There is also a large financial cost associated with their use. As such, these control options are not recommended for immediate use as remedial management options.

Artificial aeration is another potential short to medium-term remedial option aimed at breaking down water column stability (stratification which promotes algal growth) and creating oxygenated conditions in the water column which would limit the release of nutrients from the sediment. Currently, there is no evidence of seasonal stratification so this option can only be considered following a comprehensive investigation of stratification patterns in the Lake.

Dredging of the Lake sediments was considered as a remedial management options to reduce the pool of nutrients in the Lake. The large financial costs associated with dredging and the impacts on the Lake ecosystem resulted in this options not being recommended.

Ultimately, Lake Hamilton requires long-term remedial management in order to address the problem of eutrophication and thereby mitigate the current Cyanobacterial blooms. Such long-term measures should be aimed at reducing nutrient inputs in the Grange Burn and reduce the chances of formation of blooms. Significant catchment management actions, such as the introduction of riparian buffer strips, stabilisation of riparian zones and improved farming practices are required to limit the entry of nutrients via inflows and further eutrophication. Maintenance and even enhancement of aquatic macrophytes was also identified as an important management option as they have the capacity to reduce nutrient levels as they grow. Reduction of nutrient levels can also be achieved by the construction of a treatment wetland upstream of the Lake on the Grange Burn and by introducing stormwater treatment swales at the entrance point of stormwater drains.

In summary, the overriding recommendations for improving water quality in Lake Hamilton and preventing the formation of Cyanobacterial blooms are:

- ***Construction of stormwater treatment swales;***
- ***Construction of Grange Burn treatment wetland;***
- ***Maintain, protect and even enhance aquatic macrophytes in the Lake; and,***
- ***Prevention of nutrient inputs to the Lake through large scale catchment management.***

1 Introduction

Lake Hamilton is located in the Victorian western district town of Hamilton (Figure 1-1). The Lake was created in 1977 and is fed by the Grange Burn that flows through predominately agricultural land. Other inputs to the Lake include urban stormwater and overland flow. The Lake is a popular recreational area for aquatic activities such as swimming, water skiing rowing and fishing. Other recreational activities include walking, jogging and bird watching. A large all-abilities adventure playground is also being constructed at the beach area of the Lake in 2012 and is expected to attract additional users. Lake Hamilton has a high environmental, social and economic value to Hamilton and the regional community (RDC 2006; Vinall 2001).

As part of its management responsibilities, the Southern Grampians Shire Council (SGSC) conducts a monitoring program to assess water quality, Cyanobacteria (Blue Green Algae) and *Escherichia coli* (*E. coli*) in the Grange Burn, urban stormwater drains and within the Lake itself. Recurring high levels of Cyanobacteria and *E. coli* have resulted in the SGSC erecting warning signs at the Lake to inform the public of potential health issues. The most recent event occurred in early January 2012 due to high levels of Cyanobacteria including the toxic species *Nodularia spumigena* (pers. comm. Pauline Porter - SGSC). It is thought that the high Cyanobacterial levels are related to excessive nutrients entering and/or contained within the Lake (pers. comm. Stephen Ryan – Glenelg Hopkins Catchment Management Authority).

The long term viability of the Lake as a high environmental, social and economic asset to the Hamilton region ultimately depends on improving and maintaining its ecological health. Consequently, the Regional Development Company (RDC 2006) has recommended that the SGSC, in conjunction with user groups and the Grange Burn Stakeholder Action Group review and develop a management plan to address the water quality issues. As part of the preparation of a management plan, the SGSC has requested that the ALS Water Sciences Group investigate the possible causes of the high levels of nutrients, Cyanobacteria and *E. coli* in the Lake and highlight potential remedial management options (i.e. a Water Quality Action Plan). The overall approach of the investigation was to:

- ***Conduct a project inception meeting with the SGSC and a site inspection of Lake Hamilton and the Grange Burn.*** The aim of the inception meeting was to formally discuss the current water quality issues associated with the Lake and outline a suitable approach for this investigation. The site inspection was to visually inspect the current health of the Lake and the Grange Burn and to inspect the physical attributes of the stormwater drains. Sediment samples were also collected during the site inspection to assess benthic nutrients levels (see Section 2.5).
- ***Review the SGSC monitoring program and data to assess the water quality of the Grange Burn, the stormwater drains and the Lake.*** The SGSC monitoring data were reviewed and the results compared to relevant water quality guidelines for recreational use and the protection of aquatic ecosystems. The monitoring data review was carried out to determine the quality of water in the Grange Burn, the stormwater drains and within the Lake itself based on data collected by the SGSC since 2006. This review allowed recommendations to be made with regard to potential amendments to the monitoring program to further increase the knowledge of water quality dynamics in the Lake as an aid in its management.
- ***Review the physical, physico-chemical and biological characteristics of the Lake.*** The physical (e.g. depth, surface area), physico-chemical (e.g. temperature, nutrients) and biological (e.g. algal communities, aquatic plants) characteristics were examined using a combination of information from the monitoring program and other available literature. The review allowed an understanding of long-term seasonal changes in the Lake and how these contribute to water quality deterioration including the formation of Cyanobacterial blooms and persistence of high levels of *E. coli*.

- ***Conduct a Risk Assessment to identify the potential water quality,* E. coli *and Cyanobacterial risks associated with the Lake.*** The Risk Assessment was carried out using data and information obtained from the previously discussed components of this investigation. The Risk Assessment used an internationally accepted methodology aimed at identifying and prioritising the risks to user groups from adverse water quality including Cyanobacterial blooms and high *E. coli* levels. The outcomes of the Risk Assessment will assist the SGSC to:
  - Identify potential causes of the poor water quality and high Cyanobacterial and *E. coli* levels,
  - Effectively monitor, predict and manage Cyanobacterial blooms and *E. coli* levels,
  - Identify and prioritise potential remedial management actions to ameliorate the risks of Cyanobacteria blooms and high *E. coli* levels and improve water quality in the short-to-medium term,
  - Identify and prioritise potential remedial management actions to ameliorate the formation of Cyanobacterial blooms and *E. coli* levels in the long-term and ensure that Best Management Practices (BMP) are utilised, and
  - Manage adverse impacts to the environment and user groups that could arise from the poor state of the Lake while rehabilitation actions are undertaken.

Ultimately, this investigation was aimed at increasing the understanding of water quality issues, Cyanobacterial and *E. coli* dynamics in Lake Hamilton and identifying the most appropriate short-to-medium term remedial management options to mitigate those water quality problems. The short to medium-term mitigation options available include artificial aeration, algicides and controlled water releases. The long-term options to prevent Cyanobacterial blooms and high levels of *E. coli* from occurring include considerations of nutrient mitigation strategies such as upstream treatment wetlands, vegetated riparian buffer strips, riparian zone rehabilitation, and modified/improved farming practices (e.g. limiting stock access to waterways, fencing and stabilisation of river banks).

Consideration was given to the above approach in the layout of this report and as such, the report has been divided into separate sections. Section 1 is an overall introduction to the investigation. Section 2 discusses the SGSC monitoring program and data and potential amendments to the program. Section 3 examines the seasonal changes in the Lake with emphasis on the formation of Cyanobacterial blooms and high levels of *E. coli*. Section 4 incorporates all information into the Risk Assessment. Recommendations are made as to potential short and long-term remedial management actions that may be adopted by the SGSC in Section 5. Finally, a brief outline on the steps required in the design of treatment wetlands and stormwater swales is made in Section 6.

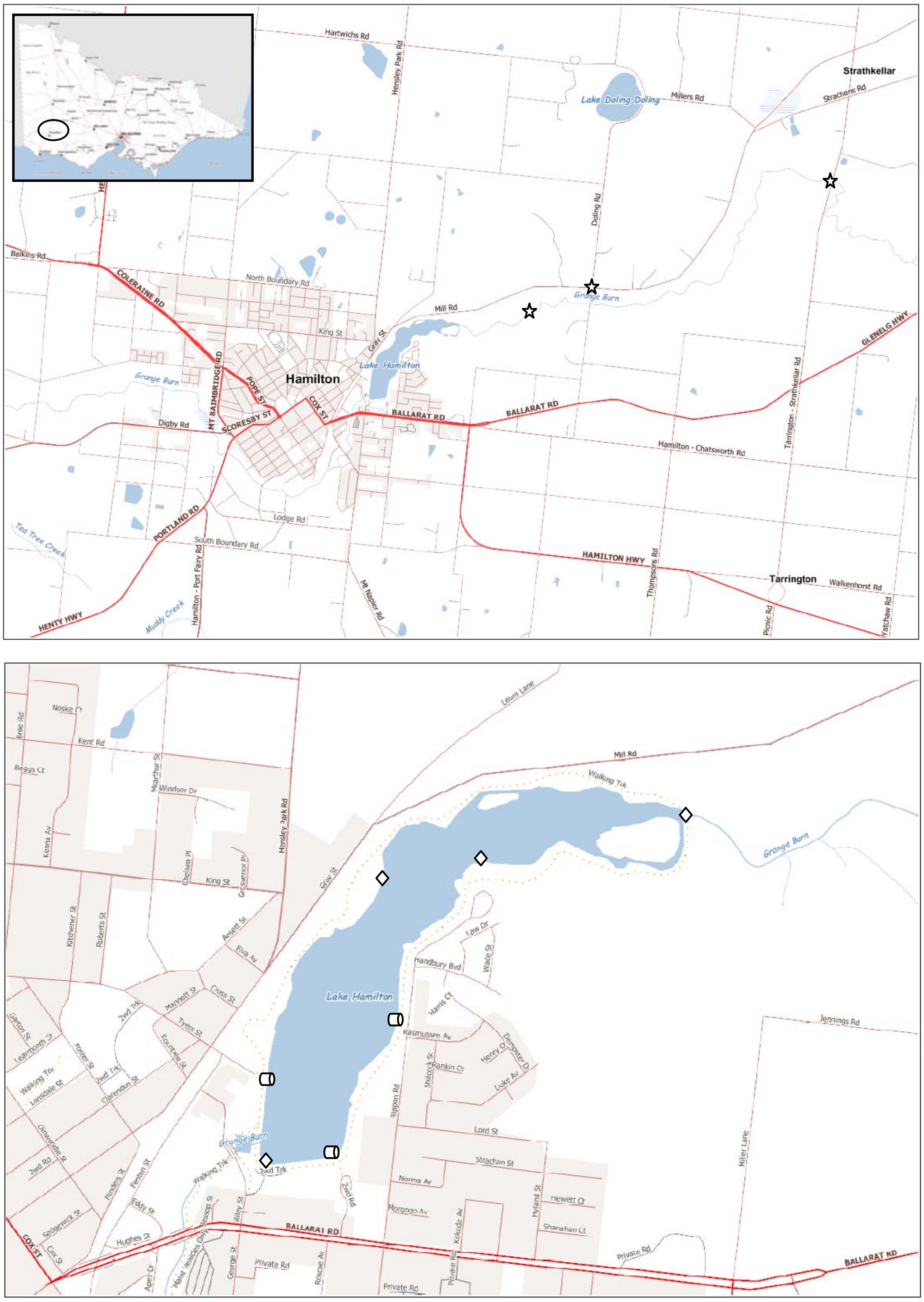


Figure 1-1. Location of Lake Hamilton and the Southern Grampians Shire Council Monitoring Sites. ☆ = Grange Burn sites, ◇= Lake Hamilton sites, ◫ = stormwater sites. Source: Map reproduced from Biodiversity Interactive Map © The State of Victoria Department of Sustainability and Environment 2012

2 Southern Grampians Shire Council Monitoring Program

The SGSC monitors surface water quality at three sites on the Grange Burn, four sites within Lake Hamilton and three stormwater drains (Figure 1-1). Algal samples are only collected from the four lake monitoring sites which are subsequently pooled to form a single composite sample. Generally, samples are collected weekly during the peak usage period from spring to summer and fortnightly in other seasons (Table 2-1). However, if an algal bloom or adverse water quality conditions are observed during autumn and winter, the monitoring frequency is increased with samples collected weekly.

Table 2-1. Details of the Southern Grampians Shire Council monitoring program of Lake Hamilton, the Grange Burn and stormwater drains

Site Type	Site Location	Water Quality and Algal Monitoring Frequency	Number of Water Quality Monitoring Occasions	Number of Algal Monitoring Occasions
Grange Burn	Tarrington-Strathkellar Rd	Autumn-Winter Fortnightly Spring-Summer Weekly	16 from early to mid 2011	NA
	Robson's Rd	Autumn-Winter Fortnightly Spring-Summer Weekly	16 from early to mid 2011	NA
	Mill Rd	Autumn-Winter Fortnightly Spring-Summer Weekly	11 from early to mid 2011	NA
Lake	Pedestrian Bridge	Autumn-Winter Fortnightly Spring-Summer Weekly	53 from late 2008 to mid 2011	2009-2010: 16 from late 2009 to mid 2010 2010-2011: 24 from mid 2010 to mid 2011
	Beach	Autumn-Winter Fortnightly Spring-Summer Weekly	77 from early 2006 to mid 2011	
	Boat Ramp	Autumn-Winter Fortnightly Spring-Summer Weekly	76 from early 2006 to mid 2011	
	Spillway	Autumn-Winter Fortnightly Spring-Summer Weekly	76 from early 2006 to mid 2011	
Stormwater	Cross St Grass Swale	Autumn-Winter Fortnightly Spring-Summer Weekly	5 early to mid 2011	NA
	Rippon Rd Frog Pond	Autumn-Winter Fortnightly Spring-Summer Weekly	5 early to mid 2011	NA
	Lakeside Mede	Autumn-Winter Fortnightly Spring-Summer Weekly	5 early to mid 2011	NA

The data collected from the SGSC monitoring program are presented and discussed below. The data have been presented for each month that monitoring has occurred in order to identify if there are any seasonal patterns. Where possible, the data have been compared to the State of the Environment Protection Policy (SEPP) water quality objectives for rivers and streams see (Vic. Gov. 2003). The relevant SEPP water quality objectives are those listed for lowland rivers in the Glenelg Basin situated within the Murray and Western Plains (see Vic. Gov. 2003 Tables A1 and A6). Where no SEPP objective existed for a particular water quality parameter, the default trigger values developed by the Australian and New Zealand Environment and Conservation Council were used (ANZECC 2000). The relevant

ANZECC default trigger values are those listed for the protection of aquatic ecosystems in 'slightly disturbed' ecosystems in south-east Australia (see ANZECC 2000 Table 3.3.2). For the Grange Burn and the stormwater drains the monitoring data were compared to the ANZECC default trigger values for lowland rivers. The Lake Hamilton monitoring data were also compared to the ANZECC default trigger values for lowland rivers as it was historically part of the Grange Burn (as has been previously done by Vinall 2001). Additional comparisons to the ANZECC default trigger values for lakes and reservoirs were also made for the lake sites. There is no temperature trigger value for the protection of aquatic ecosystems so the trigger value for the protection of recreational water quality and aesthetics was used (see ANZECC 2000 Table 5.2.2).

It should be noted that comparisons to the SEPP water quality objectives requires a minimum of 11 data values collected monthly over a one year period (see Vic. Gov. 2003 Part VIII Schedule A). The majority of the SGSC monitoring data did not satisfy this requirement and as such, comparisons to the SEPP objectives in this report represent only a 'snapshot' of the water quality conditions. This is also the case for *E. coli* where five samples collected at regular intervals within a month is required. The full list of water quality guidelines used in this investigation is contained in Table 2-2.

Table 2–2. Water quality guidelines for the assessment of aquatic health

Relevant Guideline Source	Parameter	Guideline Value
SEPP - Murray and Western Plains, lowland reaches of the Glenelg Basin	Total Phosphorus (TP - mg/L)	75th Percentile ≤ 0.04
	Total Nitrogen (TN - mg/L)	75th Percentile ≤ 0.90
	Electrical Conductivity (µS/cm)	75th Percentile ≤ 1500
	pH	75th Percentile ≤ 8.3 75th Percentile ≤ 6.5
	E. coli (orgs/100 mL)	Median: Primary Contact ≤ 150 Secondary Contact ≤ 1000
ANZECC - Protection of aquatic ecosystems, slightly disturbed ecosystems in south-east Australia	Oxidised Nitrogen (NOx - mg/L)	Lowland Rivers 0.04 Lakes & Reservoirs 0.01
ANZECC – Recreation water quality and aesthetics	Temperature (°C)	15 - 35
	Total Algae Cell Counts (cells/mL)	15,000 – 20,000
	Toxic Cyanobacteria Cell Counts(cells/mL)	15,000 – 20,000
NHMRC – Managing risks in recreational water	Total Algae Biovolume (mm^3/L)	10
	Toxic Algae Biovolume (mm^3/L)	4

Notes.

1. *For algal cell counts the minimum 15,000 cells/mL was used as a precautionary approach*
2. *Recreational water use categories: Primary Contact - such as swimming, water skiing and diving in which the user comes into direct contact with the water; Secondary contact - such as boating, wading and fishing where there is less frequent body contact with the water; and Passive recreational use, for visual and aesthetic enjoyment where there is no contact*

2.1 Hydrology

No records are currently collected with regard to water levels in Lake Hamilton (pers. comm. Aaron Kennett – SGSC). There are water level gauges at two locations within the Lake so water level can be readily recorded during the SGSC monitoring program.

2.2 Physico-chemical Parameters

The physico-chemical parameters monitored by the SGSC included pH, electrical conductivity and temperature. The results for Lake Hamilton, Grange Burn and the stormwater drains and comparisons to the relevant water quality guidelines are presented in Table 2-3. The pH levels of the Grange Burn and the stormwater drains remained within the SEPP guideline range throughout the monitoring period. However, from December 2009 to August 2010 high pH levels (i.e. alkaline) in the Lake led to non-compliance with the SEPP water quality guideline range.

Dramatic changes in pH can directly affect the physiological functioning of aquatic biota including enzyme and membrane processes (Waterwatch Victoria 2009). Low pH is reported to adversely impact on fish and macroinvertebrates by interrupting physiological functioning, decreasing spawning success and diminishing the number of successful egg hatches (Waterwatch Victoria 2009). Changes in pH can also lead to indirect effects by modifying other stressors (ANZECC 2000). For example, increasing pH levels increases the toxicity of ammonia while decreases in pH can increase the toxicity of some metals (Waterwatch Victoria 2009). Vinall (2001) indicates that a pH range greater than 8.5 is optimal for the growth of Cyanobacteria.

It should also be noted that dissolved oxygen and pH vary during the day due to photosynthesis and respiration by phytoplankton (i.e. algae). In highly productive lakes, such as Lake Hamilton, these changes can be quite marked. In most shallow lakes, pH tends to increase during the day as photosynthesis by aquatic plants and algae occurs. Furthermore, rain is often acidic and the relatively dry period from late 2009 until early 2011 may have contributed to an increase in pH during this period (see Figure 3-1). Despite this variation in pH, the changes are usually transient and often do not have any notable impact on aquatic ecosystems.

Electrical conductivity in the Grange Burn and Lake Hamilton was consistently high throughout the monitoring period. Conductivity is an indicative measure of the total concentration of salts (cations and anions) in solution (ANZECC 2000). In western Victoria groundwater is a major contributor of water and is naturally high in salt levels compared to other regions (Waterwatch Victoria). Salinity of waterways in western Victoria can reach critical levels even after a short period of no flow (Waterwatch Victoria 2009). The monitoring data suggests that saline water from the Grange Burn contributes to the high electrical conductivity of Lake Hamilton; particular following the warmer and drier periods of the year. This is also indicated by the typical late summer levels reported for western Victorian waterways of 2,000 – 10,000 µS/cm (Waterwatch Victoria 2009). Furthermore, following a prolonged dry period salinity can reach 6,000 – 40,000 µS/cm (Waterwatch Victoria 2009). Electrical conductivity above 1500 µS/cm is known to be harmful to freshwater aquatic organisms (ALS 2011; Waterwatch Victoria 2009). However, it is thought that aquatic fauna of western Victoria may be more tolerant to high salinity levels due to the naturally occurring salinity levels of the region (Lind 2006).

Water temperatures in the Grange Burn from March to June 2011 were less than the ANZECC minimum guideline of 15°C for recreational use. In Lake Hamilton, low water temperatures were also observed from June to October 2010 and April to June 2011. Water temperatures less than 15°C can be stressful to users not wearing appropriate protective clothing – especially during prolonged immersion (ANZECC 2000). This is not an issue with regard to the Grange Burn as it is assumed that it is rarely used for recreational activities such as swimming. Lake Hamilton is occasionally used for recreational swimming and other indirect contact activities so caution should be used during the cooler periods of the year when water temperatures are low. Despite the potential risks of cold water, a 'common sense' approach by user groups should eliminate any risk. In terms of preventing the formation of Cyanobacterial blooms, colder is preferred to warmer water.

Table 2-3. Physico-chemical parameters in the Grange Burn, stormwater drains and Lake Hamilton

Site Type	Date	Median Temperature (°C)	25th & 75th Percentiles pH (pH units)	25th & 75th Percentiles Electrical Conductivity (µS/cm)
Grange Burn	January 2011	20.4	7.4 - 7.9	2050 - 2675
	February 2011	17.0	7.8 - 7.9	3400 - 4400
	March 2011	14.6	7.7 - 7.9	5250 - 6250
	April 2011	13.7	8.2 - 8.3	4375 - 5125
	May 2011	11.0	7.9 - 8.0	4150 - 6300
	June 2011	8.1	7.6 - 7.8	3400 - 5200
Stormwater Drains	January 2011	21.0	7.2 - 7.4	245 - 335
	April 2011	N/A	7.8 - 8.0	285 - 425
	May 2011	N/A	7.3 - 7.6	N/A
Lake Hamilton	December 2009	19.0	7.8 - 8.4	2045 - 2105
	January 2010	22.3	8.4 - 8.5	2240 - 2368
	February 2010	22.9	9.0 - 9.3	2310 - 2383
	March 2010	18.6	8.3 - 8.8	189 - 2453
	April 2010	15.7	8.4 - 8.7	2253 - 2440
	May 2010	15.4	8.3 - 8.5	2310 - 2483
	June 2010	9.6	8.3 - 8.4	2373 - 2533
	July 2010	9.2	8.6 - 8.6	2300 - 2350
	August 2010	9.3	8.0 - 8.4	3100 - 3350
	September 2010	14.2	7.3 - 7.4	408 - 420
	October 2010	13.9	7.7 - 7.8	1375 - 1600
	November 2010	17.1	7.9 - 8.1	1775 - 1875
	December 2010	23.1	8.1 - 8.3	1700 - 1850
	January 2011	23.1	7.1 - 7.6	638 - 870
	February 2011	20.2	7.5 - 7.7	835 - 913
	March 2011	18.3	7.5 - 7.6	1000 - 1200
	April 2011	14.8	8.0 - 8.2	1400 - 1750
	May 2011	12.1	8.1 - 8.3	2175 - 2500
	June 2011	10.0	7.9 - 8.1	2275 - 3125
Guideline		**15 - 35°C**	**6.5 - 8.3**	**≤1500µS/cm**

Notes.

1. *Red shading indicates non-compliance with relevant water quality guidelines*
2. *N/A indicates no data collected or available*

2.3 Nutrients

Excessive nutrients in waterbodies, particularly nitrogen (N) and phosphorus (P), are one of the key causes of algal blooms. In natural circumstances, the sources of P and N in waterways are the weathering of rocks (inorganic forms) and the decomposition of plant and animal material (organic forms) (Waterwatch 2009). However, in Australia the soils are typically low in P concentrations compared to other continents and the use of superphosphate fertilizer is common in agriculture (Vinall 2001). This can lead to unnatural increases in P being delivered to waterways which increases the potential for algal blooms (discussed further below).

There are different forms of N in waterways that include total Kjeldahl N (TKN) and oxides of N (NOx). The TKN form represents organic N that can be broken down by bacteria and converted into more readily available forms (Waterwatch 2009). The NOx forms of N, along with ammonia/ammonium are the most available form for the uptake by plants (Waterwatch 2009). Total N (TN) is the combination of TKN and NOx.

Phosphorus is rarely found in its elemental form (P) but usually occurs in waterways as inorganic and organic forms of phosphate (PO_4^{-3}). Both inorganic and organic PO_4^{-3} can be dissolved in the water or attached to particles in the water column or sediment. Inorganic forms of PO_4^{-3} include orthophosphates and condensed phosphates. Orthophosphates are readily available to plants while condensed phosphates are complex, tightly bound compounds often referred to as polyphosphates (Waterwatch 2009). Organic PO_4^{-3} refers to a PO_4^{-3} molecule associated with a carbon-based molecule such as those found in plant or animal tissue (Waterwatch 2009). Total P (TP) is the sum of organic and inorganic forms of P in unfiltered water samples (Waterwatch 2009).

The monitoring of nutrients by the SGSC included recordings of TP, TKN, NOx and TN. The results for Lake Hamilton, the Grange Burn and the stormwater drains and comparisons to the relevant water quality guidelines are presented in Table 2-4. The SGSC monitoring data indicates that excessive nutrients in Lake Hamilton, the Grange Burn and the stormwater drains, particularly TN, NOX and TP, were consistently observed during the monitoring period. The high concentrations of nutrients, which promote algal growth, are well above the relevant water quality guidelines for the protection of ecosystem health.

The growth of algae in a waterbody is not only influenced by the concentrations of nutrients but also the ratio of Carbon (C), N and P (C:N:P - Redfield Ratio). The Redfield ratio (or Redfield stoichiometry) is defined as the molecular ratio of C, N and P in plankton. The ratio was originally developed by Alfred Redfield in 1934 when he discovered that in marine environments the elemental composition of organic matter (alive and dead) was remarkably constant with a C:N:P ratio of 106:16:1. In contrast, there can be marked deviations from this ratio in freshwater lakes (Wetzel 2001) due to processes such as seasonal nutrient cycling and nutrient loading from external sources.

With regard to the formation of algal blooms in lakes, the ratio of N:P is of utmost importance (Wetzel 2001). Generally, the Redfield ratio of 16:1 indicates that both N and P are in sufficient concentrations relative to one another to allow continued algal growth. Deviations from the 16:1 ratio indicate the nutrient that limits algal growth (Wetzel 2001). That is, a ratio >16 suggest that there is an excess of N compared to P and the growth of algae are limited by P. In this case algae will continue to grow until all P has been utilised. Alternatively, a ratio of <16 indicates that N is the limiting nutrient and the growth of algae will occur until all N is utilised. In a natural Lake ecosystem, P limitation tends to be much greater than N limitation (Wetzel 2001). However, the application of superphosphates in the catchment can lead to an increase in P in a waterbody, thereby resulting in N limiting conditions.

Many Cyanobacteria are efficient N fixers and can utilise atmospheric N_2 sources. This allows continued growth of the Cyanobacterial population despite N being the limiting nutrient in a waterbody. Due to this capability, a Redfield ratio of <16 is reported as favourable to the growth of Cyanobacteria compared to other algal taxon (Cullen *et. al.* 1993; Vinall 2001; ALS 2011). The monitoring data indicates that the N:P ratio in Lake Hamilton was regularly favourable to the growth of Cyanobacteria with values regularly ≤16 (Table 2-4).

Table 2-4. Nutrient concentrations from the Grange Burn, stormwater drains and Lake Hamilton

Site Type	Date	25th & 75th Percentiles TP (mg/L)	Median TKN (mg N/L)	Median NOx (mg N/L)	25th & 75th Percentiles TN (mg/L)	N:P Ratio
Grange Burn	January 2011	0.158 - 0.193	2.85	**0.076**	2.7 - 3.1	17
	February 2011	0.064 - 0.097	1.40	**0.046**	1.4 - 1.7	17
	March 2011	0.023 - 0.052	1.15	**0.055**	1.2 - 1.2	29
	April 2011	0.210 - 0.350	2.10	**0.570**	2.3 - 3.0	9
	May 2011	0.029 - 0.065	1.30	0.032	1.3 - 1.7	29
	June 2011	0.047 - 0.205	1.85	**0.750**	1.6 - 3.3	21
Stormwater Drains	January 2011	0.113 - 0.140	1.20	**4.200**	3.5 - 5.7	39
	April 2011	0.107 - 0.135	1.30	**4.000**	3.9 - 5.5	41
	May 2011	0.074 - 0.180	0.77	**0.580**	0.8 - 1.8	12
Lake Hamilton	July 2010	0.024 - 0.032	1.20	0.013	1.2 - 1.3	18
	August 2010	0.021 - 0.062	1.40	**0.935**	1.3 - 2.8	27
	September 2010	0.218 - 0.230	3.10	**0.470**	3.4 - 3.6	12
	October 2010	0.081 - 0.086	2.30	0.030	2.2 - 2.3	16
	November 2010	0.088 - 0.094	1.90	**0.091**	2.0 - 2.1	9
	December 2010	0.053 - 0.057	1.80	0.012	1.6 - 1.8	31
	January 2011	0.270 - 0.363	2.80	0.014	2.6 - 2.9	5
	February 2011	0.333 - 0.373	2.70	**0.115**	2.7 - 3.0	10
	March 2011	0.235 - 0.263	2.20	**0.265**	2.4 - 2.5	4
	April 2011	0.175 - 0.210	1.90	**0.215**	2.0 - 2.5	11
	May 2011	0.052 - 0.080	1.70	0.003	1.6 - 1.9	14
	June 2011	0.036 - 0.044	1.40	0.003	1.4 - 1.4	22
Guideline		**≤ 0.04 mg/L**	**N/A**	**0.01 mg N/L 0.04 mg N/L**	**≤0.09 mg/L**	**< 16**

Notes.

1. *Red shading indicates non-compliance with relevant water quality guidelines*
2. *For NOx, the bold text indicates non-compliance with both river (0.04) and lake (0.01) guidelines*

2.4 *Escherichia coli* (*E. coli*)

E. coli levels in the Grange Burn and the stormwater drains were consistently high throughout the monitoring period (Table 2-5). Although the *E. coli* inputs into Lake Hamilton have been excessive, the Lake itself has remained generally compliant with the water quality guidelines. The *E. coli* water quality guideline was only exceeded in February 2009 and September 2010. Faecal contamination, of which *E. coli* is an indicator, can potentially lead to human health risks from disease-causing pathogens. Pathogens may include bacteria such as *Vibrio cholerae* and *Salmonella*, viruses such as Hepatitis A, and parasites such as *Giardia* and *Cryptosporidium* (Waterwatch 2009).

The source of the pathogens in the Grange Burn and the stormwater drains is currently unknown. It can be reasonably assumed however, that faecal matter from stock in the Grange Burn catchment is the major source of *E. coli* to the Grange Burn (see Plate 1). The *E. coli* in the stormwater drains will need to be investigated further should it continue to be an issue. Microbial Source Tracking (MST) methods can be used to identify the source of the faecal matter (i.e. human or animal) as a first step in the management of contamination in the waterbodies (see ALS 2011a).

Plate 1. Example of agriculture in the Grange Burn catchment and the potential for faecal matter from stock to enter the waterway. Note that the pasture extends to the water's edge and the lack of significant riparian vegetation

The *E. coli* concentrations in the Grange Burn may be misleading due to low water levels and little stream flow. During the time of monitoring by the SGSC, the Grange Burn was often not flowing and this may have led to assessing *E. co*li in stagnant pools (pers. comm. Stephen Ryan – Glenelg Hopkins Catchment Management Authority). This may explain why *E. coli* levels in the Lake have remained relatively low compared with the Grange Burn. It should also be noted that *E. coli* and other bacteria do not persist for long in the environment and their abundance may change rapidly due to die-off.

Table 2-5. *E. coli* concentrations from the Grange Burn, stormwater drains and Lake Hamilton

Site Type	Date	Median *E. coli* (orgs per 100 mL)
Grange Burn	January 2011	475
	February 2011	160
	March 2011	415
	April 2011	**2300**
	May 2011	120
	June 2011	**4490**
Stormwater Drains	January 2011	**1200**
	April 2011	**2700**
	May 2011	460
Lake Hamilton	January 2006	87
	February 2006	40
	March 2006	70
	April 2006	50
	May 2006	22
	June 2006	12
	February 2007	10
	March 2007	15
	April 2007	65
	November 2007	1
	January 2008	30
	February 2008	80
	December 2008	16
	January 2009	14
	February 2009	150
	March 2009	45
	April 2009	120
	December 2009	20
	January 2010	20
	February 2010	20
	March 2010	20
	April 2010	90
	May 2010	100
	June 2010	80
	July 2010	10
	August 2010	36
	September 2010	570
	October 2010	16
	November 2010	10
	December 2010	15
	January 2011	33
	February 2011	40
	March 2011	27
	April 2011	94
	May 2011	10
	June 2011	52

Notes.

1. *Red shading indicates non-compliance with relevant water quality guideline for primary contact*
2. *Bold test indicates non-compliance with relevant water quality guideline for secondary contact*
3. *The water quality guidelines were <150 per 100 mL for primary contact and <1000 mL for secondary contact*

2.5 Sediments

The Regional Development Company (2006) suggested that the sediments in Lake Hamilton are likely to be a major store of nutrients that contribute to algal blooms. The SGSC also acknowledged that the nutrient content of the sediments was largely unknown (pers. comm. Kylie McIntyre – SGSC). Due to this, sediment samples were collected from four sites as part of this investigation during December 2011. The sites were located on the eastern and western sides of the Lake, at the pedestrian bridge where the Grange Burn enters, and near to spillway. The spillway site was included to ensure that a sample was collected from the deepest part of the Lake. At each site, five Ekcman Grab samples were collected to encompass any potential variability in the nutrient content of the sediments. These replicate samples were subsequently pooled to form a composite sample at each site. The results of the sediment analyses are presented in Table 2-6 along with sediment nutrient data that had been previously collected by Vinall (2001).

Table 2–6. Nutrient concentrations in the sediments of Lake Hamilton

Study	Collected	Site	Estimated Water Depth	Total Nitrogen TN (mg N/kg)	Total Phosphorus TP (mg/kg)
Current ALS Study	Dec 2011	East Bank	2.0 m	6100	550
	Dec 2011	West Bank	2.5 m	1600	160
	Dec 2011	Pedestrian Bridge	2.5 m	6400	750
	Dec 2011	Spillway	4.0 m	9000	670
	Average			**5775**	**533**
Vinall 2001	Aug 1998	1	4.0 m	2207	445
	Aug 1998	2	2.5 m	2124	505
	Aug 1998	3	2.0 m	1822	410
	Nov 1998	1	4.0 m	2584	625
	Nov 1998	2	2.5 m	2223	555
	Nov 1998	3	2.0 m	2208	630
	Sept 1999	1	4.0 m	858	430
	Sept 1999	2	2.5 m	1170	525
	Average			**1900**	**516**

Notes.

1. No guidelines for the concentration of nutrients in sediments currently exist

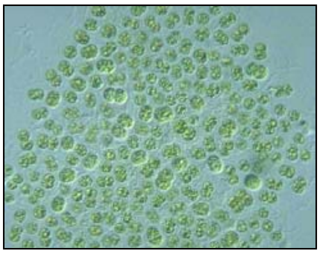
The sediment data indicates that P concentrations have remained relatively consistent between the investigation carried out by Vinall (2001) and the current monitoring program. However, there appears to have been a large increase in N concentrations associated with the sediments. The source of the N in the sediments is not known. Two possible sources are decomposing organic matter that have accumulated in the Lake sediments (i.e. deceased algal, plant matter or aquatic fauna), or the transport of N bound to sediments from the Grange Burn.

Phosphorus levels in the sediments of Lake Hamilton are higher than levels reported for six other lakes in eastern Victoria (see AWT 2000). For instance, in the ATW (2000) report, Lake Batyo Catyo was found to have the highest P concentrations of around 250 mg/kg while Dock Lake and areas of Rocklands Reservoir were around 200 mg/kg. Total N content of the sediments was not assessed in the study but TKN (organic nitrogen) ranged from approximately 2100 to 400 mg/kg. In another study of 12 northern Victorian water storages, the median TP and TN concentrations of the sediments were 464 and 3075 mg/kg respectively (see Water Ecoscience 1996). The median results in this study (using data collected in 2011 only) were 610 and 6250 mg/kg of TP and TN respectively. These comparisons suggest that high concentrations of nutrients in the sediments of Victorian lakes and reservoirs are a common issue and that Lake Hamilton is no exception.

2.6 Blue Green Algae - Cyanobacteria

Although most Cyanobacteria are not harmful, blooms can present major problems to the functioning of a waterbodies ecosystem. For instance, as an algal bloom diminishes and the algae decompose, dissolved oxygen is consumed potentially leading to anoxic and odorous conditions in the waterbody.

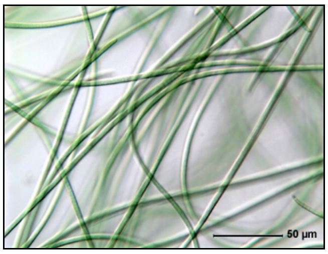
Some Cyanobacteria do produce toxins that can be harmful and potentially lethal to humans, livestock and birds (Falconer 1993; Carmichael 1994; Humpage *et. al*. 1994). The four main toxic Cyanobacteria in Australia are *Microcystis* spp. including *M. aeruginosa*, *Anabaena circinalis*, *Cylindrospermopsis raciborski* and *Nodularia* spp. (Plate 2). Some of these produce hepatotoxins which damage the liver and other internal organs while others produce neurotoxins which affect neuromuscular performance. In addition, some Cyanobacteria also produce lipo-polysaccharides that can lead to skin irritations (BGATF 1992; Falconer 1993). All four of the toxic Cyanobacteria mentioned above have been found in Lake Hamilton. Less toxic but very common Cyanobacterial found in Australian waterbodies include filamentous forms like *Oscillatoria* spp., and colonial forms like *Aphanocapsa* spp. and *Aphanothece* spp. (Plate 2). The latter forms are similar to *Microcystis* and can often be mis-identified.



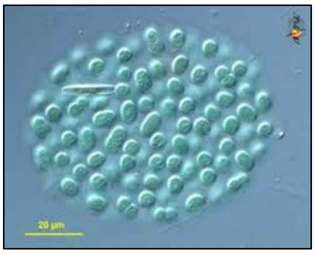
Microcystis colony

Microcystis colony

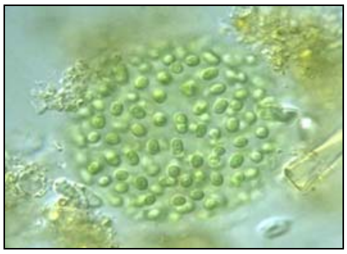
Anabaena circinalis



Oscillatoria filaments



Aphanocapsa colony



Aphanothece colony

Plate 2. Examples of toxic Cyanobacteria found in Australian freshwaters

The results of algal monitoring conducted at Lake Hamilton since December 2009 are summarised in Table 2-7. A colour coded ‘traffic light’ system has been used to identify the threat level associated with the algal abundances based on NHMRC (2008) and techniques used by other management agencies (see GMW 2011). The rationale behind the ‘traffic light’ alert level framework is outlined in Table 2-7.

Table 2-7. Cyanobacterial Alert Level Framework

Threat Level	Total Algal Biovolume	Toxic Algal Biovolume
Alert Level 1 - Low	0.04 to < 0.4 mm^3/L	0.04 to < 0.4 mm^3/L
Alert Level 2 – Medium	≥ 0.4 to 10 mm^3/L	≥ 0.4 to 4 mm^3/L
Alert Level 3 - High	≥ 10 mm^3/L	≥ 4 mm^3/L

Cyanobacterial levels above the recreational guidelines were regularly observed throughout the monitoring period. Although recreational guideline values for cell counts and biovolume levels are presented, the biovolume is the preferred guideline as it is more closely related to toxin concentrations than total cell numbers (see NHMRC 2008). Cyanobacterial abundance exceeded the Alert Level 3 total algae biovolume and the toxic algae biovolume on several occasions from December 2009 to March 2010. Excessive Cyanobacteria was also recorded during April 2011. Generally, all Cyanobacteria blooms, as indicated by biovolumes that exceeded the guidelines, occurred during the warmer months when temperature and light are more beneficial to algal growth.

Table 2-8. Lake Hamilton Cyanobacteria concentrations collected during the SGSC monitoring program

Date	Cyanobacteria (cells/ml)	Total Algal Biovolume (mm^3/L)	Toxic Algal Biovolume (mm^3/L)
7 December	76,601	6.67	6.67
14 December	129,475	11.24	11.27
7 January 2010	247	0.01	0.00
12 January 2010	8,725	0.56	0.00
2 February 2010	1,188,282	298.09	296.63
8 February 2010	1,027,006	237.81	233.37
15 February 2010	126,144	27.85	27.87
22 February 2010	787,638	196.79	196.70
1 March 2010	44,052	11.09	10.46
9 March 2010	4,952	1.83	0.05
15 March 2010	4,992	0.30	0.12
22 March 2010	4,435	0.10	0.12
29 March 2010	76,136	2.27	0.29
12 April 2010	87,139	0.54	0.00
24 April 2010	41,862	0.28	0.18
7 June 2010	132	0.00	0.00
5 July 2010	102	0.00	0.00
9 August 2010	583	0.01	0.00
7 September	4,014	0.05	0.00
18 October 2010	3,283	0.02	0.00
8 November	312	0.00	0.00
6 December	1,225	0.05	0.04
11 January 2011	40,117	1.69	1.56
17 January 2011	75,287	0.25	0.00
27 January 2011	110,091	0.30	0.00
31 January 2011	37,505	0.11	0.01
8 February 2011	4,214	0.01	0.00
21 February 2011	1,131	0.02	0.01
28 February 2011	13,539	4.47	0.03
16 March 2011	5,623	0.01	0.01
28 March 2011	4,992	0.07	0.06
12 April 2011	10,205	0.57	0.56
18 April 2011	137,197	33.11	32.71
2 May 2011	18,749	2.85	2.85
10 May 2011	14,944	1.70	1.50
16 May 2011	6,949	0.88	0.86
23 May 2011	12,920	0.70	0.45
30 May 2011	27,278	5.45	5.35
6 June 2011	11,751	0.23	0.18
21 June 2011	6,139	0.03	0.00
Guideline	**15,000 cells/mL**	**Alert Level 3: 10 mm^3/L**	**Alert Level 3: 4 mm^3/L**

2.7 Amendments to the SGSC monitoring program

This report has used data collected from the SGSC monitoring program. Water quality data have been collected from the Lake since early 2006 and from the Grange Burn and stormwater drains from early 2011. It is suggested that this monitoring should continue to increase knowledge of water quality issues over a longer time period. Algal communities and *E. coli* in the Lake have been assessed since late 2009 and should also be continued to assess the current water quality risks to user groups and any benefits of future remedial management actions aimed at addressing algal blooms. Other potential amendments to the monitoring program are listed below. These amendments have not been prioritised based on cost or expected outcomes, etc. The ALS Water Resources Group is available for further discussions on these amendments should the SGSC wish to do so.

- As noted earlier in this report (Section 2.0) valid comparisons to the SEPP water quality objectives requires a minimum of 11 data values collected monthly over a one year period (see Vic. Gov. 2003 Part VIII Schedule A). Future monitoring by the SGSC should be aimed at meeting these requirements for water quality. That is, endeavour to monitor at least monthly. More frequent monitoring may be required should adverse water quality conditions be observed. This is also the case for *E. coli* where five samples collected at regular intervals within a month is required.

- The number and location of sites in the Lake and the Grange Burn are adequate to encompass spatial variation in water quality. All sites should be retained in future monitoring.

- The stormwater drains have been identified as a source of high levels of nutrients and *E. coli* to the Lake although only three stormwater drains are currently monitored by the SGSC. Increasing the number of stormwater drains monitored may help to further quantify the water quality risks to the Lake.

- The SGSC collects algal samples from four lake monitoring sites which are subsequently pooled to form a single composite sample. While this can reduce the costs associated with processing of algal samples, there is a risk of 'masking' absolute abundances of algae. For example, consider that there are low abundances of Cyanobacteria on the eastern (leeward) shoreline but relatively high abundances on the western (windward) shoreline. Amalgamating these two samples would result in a dilution of the algal sample with high abundances. As such, the presence of a Cyanobacteria bloom may potentially be missed. Vinall (2001) found that Lake Hamilton was well mixed with little spatial differences in the distribution of algal communities. However, her findings were based on data collected over a decade ago and the algal dynamics of the Lake may currently be different. There are two recommended options to address this issue:

    - Do not amalgamate the algal samples into a single composite sample, or;

    - Visually inspect the Lake during monitoring for evidence of algal scums or 'green water' and collect samples from these locations. If there is no visual evidence of high algal abundances, then the collection of samples should occur on the leeward side of the lake in preference to the windward side. This is a common technique used in the monitoring of major water storages throughout Victoria.

- Currently, no water level data of Lake Hamilton are being collected. Changes in water level can have implications on the ecological dynamics of the Lake and should be recorded on each monitoring occasion.

- Flow data from the gauging station on the Grange Burn are also often limited. During monitoring, some brief notes on flow levels should be made (pers. comm. Stephen Ryan – Glenelg Hopkins Catchment Management Authority). For example, no flow in the Grange Burn and only standing pools. Such information can aid in analyses such as those of *E. coli*. (e.g. Are there high faecal inputs or is it an artefact of concentration in stagnant pools during low water levels?).

- Other descriptive notes should be taken during monitoring such as weather conditions, obvious signs of stock access and faecal inputs, occurrences of large filamentous algae stands.

- The Grange Burn and stormwater drains have been identified as a source of *E. coli* to the Lake. However, the cause of the *E. coli* is not currently known. There is potential for using Microbial Source Tracking (MST) methods to identify if the *E. coli* is derived from animal or human sources. Remedial management actions can then be aimed at addressing specific causes.

- The area in Hamilton that feeds each of the stormwater drains should also be determined. Knowing the drainage area of each stormwater drain would allow prompt identification of the sources of high nutrients and/or *E. coli* levels observed during the monitoring.

- Currently, there is no evidence of thermal stratification in the Lake. Anecdotal evidence suggests that the Lake may stratify during the warmer periods of the year (pers. comm. Stephen Ryan – Glenelg Hopkins Catchment Management Authority). Stratification of the Lake can have major implications on the ecological dynamics – including the formation of algal blooms. It is recommended that during monitoring, vertical profiles of temperature and dissolved oxygen are taken at 0.5m intervals from a boat in the deepest area such as near the spillway. In particular, monitoring for stratification should occur during the warmer times of the year during periods of little or no wind. It should be noted that Vinall (2001) states that Lake Hamilton is a shallow ‘polymictic’ lake that does not exhibit seasonal stratification. The Lake is also highly productive at all depths due to the euphotic depth being greater than the average depth of the Lake which may also decrease the potential for stratification (see Section 3.2). For reasons such as these is a chance that the Lake does not exhibit stratification in any season. Despite this, the influence of stratification on the formation of algal blooms can be significant in a lake ecosystem and it is considered important to definitively know if does occur.

- A stormwater treatment pond (the Frog Pond) has been established on Rippon Road on the eastern bank. It is assumed that the Frog Pond reduces sediment and nutrient transport to the Lake. This has not been formally tested and further investigation into the effectiveness of the Frog Pond could be made. This will not only increase the working knowledge of treatment ponds but can also be used as a tool to inform the community of potential benefits should other treatment ponds, wetlands, swales, etc be constructed. An R&D project currently being undertaken by the ALS Water Resources Group may aid in this once completed. Preliminary findings from a literature review are presented in Appendix A which indicates the degree of nutrient removal for different types of wetlands, swales, buffer strips etc. More details on how to assess the efficiency of such treatment options can be supplied by ALS on request.

- Aquatic macrophytes play an important role as a sink for nutrients in a waterbody. The extent of submerged macrophytes is currently not known in Lake Hamilton. It is recommended to survey the submerged macrophytes of the Lake to determine the species present and their abundance. If the submerged macrophytes community is found to be rare or absence, the addition of macrophytes such as *Vallisneria* spp. and *Hydrilla verticillata* can aid in a reduction of nutrients.

- Currently, there is no evidence that European Carp has colonised the Lake. Carp can have a significant influence on the formation of algal blooms and their presence in the Lake should be reported to relevant authorities if observed.

- An analysis of nutrients in the sediments was carried out in this investigation as it was recognized as a knowledge gap. Future sediment monitoring should take place to further investigate changes in nutrients levels over time. The frequency of sediment monitoring required to detect temporal changes is dependent on sedimentation rates (Simpson *et. al.* 2005). This is currently unknown for Lake Hamilton. It is recommended to at least monitor annually to investigate seasonal changes in sediments. The same methodology as used in this investigation is suggested (i.e. multiple samples from four sites).

- Finally, the National Health and Medical Research Council have documented the required protocols for the monitoring of Cyanobacteria and assessment of associated risks (see NHMRC 2008 Section 6). It is highly recommended that the SGSC review the NHMRC protocols to ensure that their monitoring program satisfies these protocols. An example of one component of the NHMRC (2008) protocol is included in Table 2-9.

Table 2-9. Recommended actions as different alert levels for Cyanobacteria (modified from NHMRC 2008).

Level	Recommended Actions
Surveillance Mode (Green Level)	**Regular monitoring:** 1. Weekly sampling and cell counts at representative locations in the water body where known toxigenic species are present (i.e. *Microcystis aeruginosa, Anabaena circinalis, Cylindrospermopsis raciborskii, Aphanizomenon ovalisporum, Nodularia spumigena*); or, 2. Fortnightly for other types including regular visual inspection of water surface for scums.
Alert Mode (Amber Level)	1. Notify agencies as appropriate. 2. Increase sampling frequency to twice weekly at representative locations in the waterbody where toxigenic species (above) are dominant within the alert level definition (i.e. total biovolume) to establish population growth and spatial variability in the waterbody. 3. Monitor weekly or fortnightly where other types are dominant. 4. Make regular visual inspections of water surface for scums. 5. Decide on requirement for toxicity assessment or toxin monitoring.
Action Mode (Red Level)	1. Continue monitoring as for alert mode. 2. Immediately notify health authorities for advice on health risk. 3. Make toxicity assessment or toxin measurement of water if this has not already been done. 4. Health authorities warn of risk to public health (i.e. the authorities make a health risk assessment considering toxin monitoring data, sample type and variability).

3 The Ecological Dynamics of Lake Hamilton

The ecological dynamics of lakes, such as the seasonal recurrence of Cyanobacterial blooms, are an indication of eutrophication (i.e. nutrient-enrichment) that appears to have occurred in Lake Hamilton over a period of time. To better understand the factors that are causing the Cyanobacterial blooms, in order to identify remedial management actions, it is necessary to understand the causal factors and inter-relationships of lake dynamics. Phytoplankton (including Cyanobacteria) abundance in lakes is largely influenced by the following:

- Climate (e.g. air temperature, solar radiation, rainfall);
- Physical features and hydrology (e.g. depth, surface area, inflows, water levels);
- Physico-chemical characteristics (e.g. concentrations of nutrients in the water column and sediments, N:P nutrient ratios, light penetration, turbidity, temperature and seasonal stratification); and,
- Biological characteristics (i.e. inter- and intra-specific competition among different trophic groups such as zooplankton abundance and herbivorous fish) and the availability of submerged aquatic macrophytes and riparian vegetation (as components of functional ecosystems).

A review of the above information will aid in gaining an understanding of the factors that are the primary drivers of the Lake's ecological dynamics – including the formation of Cyanobacterial blooms. It is also necessary to review all information to quantify risks and better understand the sources of pollutants (e.g. risks from pathogens as indicated by *E. coli*), so that options to remediate such risks can be assessed. The ecological dynamics of Lake Hamilton are discussed below. To date, the most comprehensive investigation of the ecology of Lake Hamilton was carried out by Vinall (2001). Much of the information discussed below stems from the work of Vinall (2001) and is acknowledged where required.

3.1 The Hamilton Region

Hamilton is a rural town in the southwest of Victoria with a population of around 10,000. It is approximately 100 km north of the coast and around 300 km west of Melbourne. The Hamilton region lies within the western district coastal plains that extend further inland to Horsham and the Little Desert National Park. There are remnant patches of native vegetation spread throughout the region that is bordered on its northeast boundary by the Grampians National Park. The major land use in the region is agriculture – particularly wool, lamb and beef. In recent years there has been an increase in the amount of cropping in the region as well as the introduction of Blue Gum plantations (Vinall 2001). Basalt rock is the dominant land type in the region (Vinall 2001). Fertilizers such as superphosphates are used throughout the region due to the typically poor phosphorus levels of the soils (Vinall 2001).

The Grange Burn is fed by several springs that usually keep the waterway flowing throughout the year (Vinall 2001). Groundwater in the region are generally low yielding and classed as brackish with electrical conductivities in the range of 900 to 3,000 µS/cm (Water Victoria 1989). Erosion, sedimentation and high nutrient levels have been identified as important issues for the Grange Burn (GHCMA 2002).

3.2 Climate of the Hamilton Region

Hamilton lies within a temperate region of Australia with relatively predictable weather conditions. The median annual rainfall at Hamilton is approximately 620 mm with summer rainfall ranging from 20 – 36 mm and winter from 60 – 76 mm (Bureau of Meteorology

2012). The median annual air temperature of the region is 19ºC with median summer temperatures of around 25ºC and winter 12-13ºC (Bureau of Meteorology 2012). Rainfall and air temperature recordings from the Bureau of Meteorology weather station at Hamilton Airport (Station #90173) for the past 10 years are displayed in Figure 3-1. Mean monthly levels of solar radiation are in Figure 3-2. Vinall (2001) also reports that the euphotic depth of Lake Hamilton (i.e. depth at which light is sufficient for algal photosynthesis) is 3 m and is greater than the average depth of the Lake.

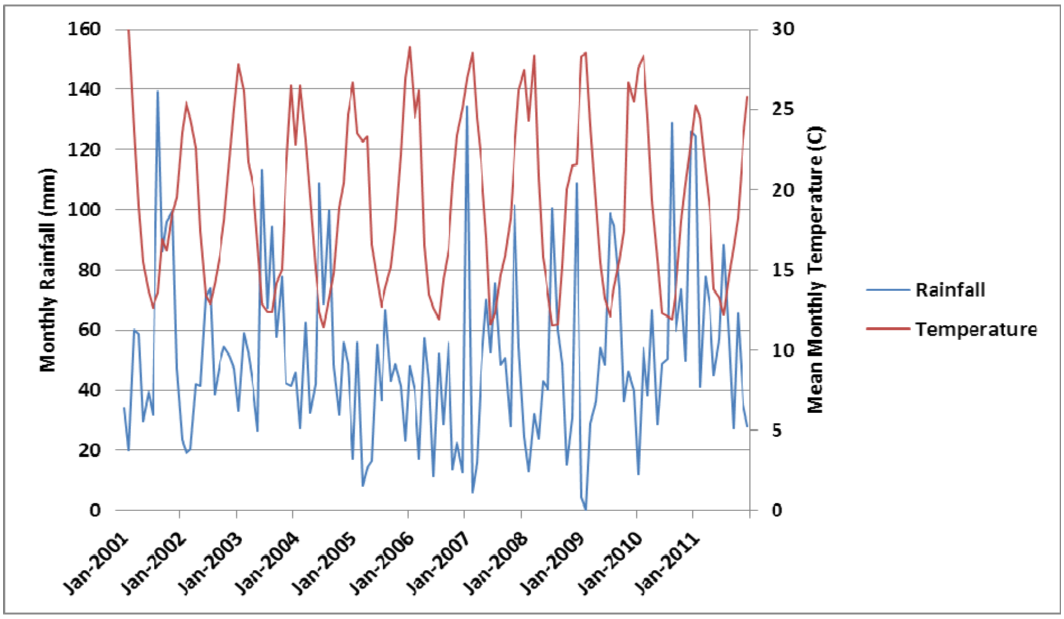


Figure 3-1. Rainfall and temperature recordings taken from the Bureau of Meteorology weather station at Hamilton Airport (Station #90173)

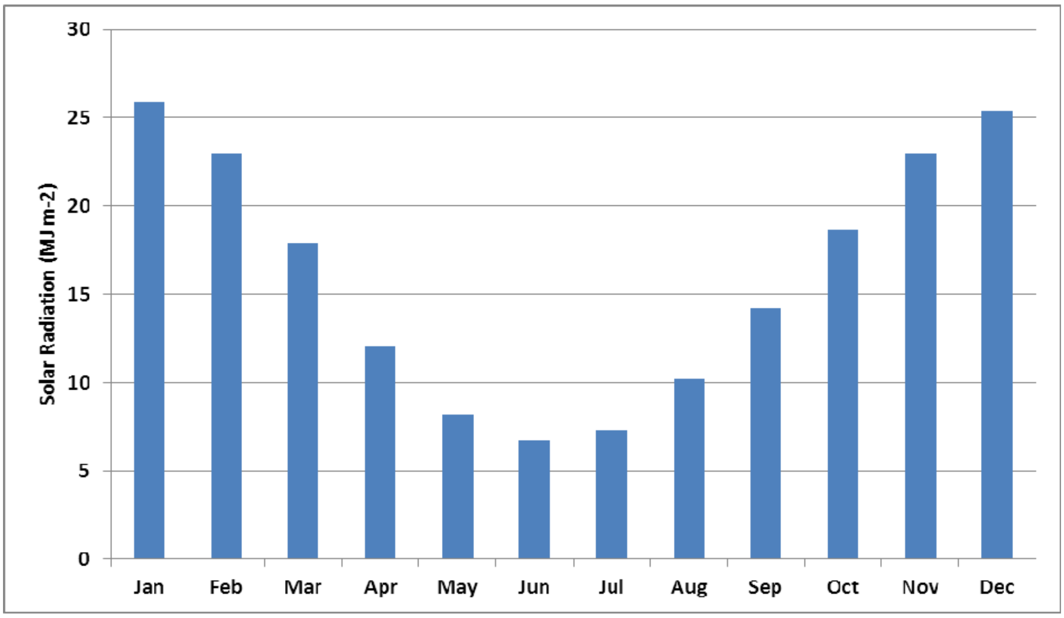


Figure 3-2. Mean monthly solar radiation recordings taken from the Bureau of Meteorology weather station at Hamilton Airport (Station #90173)

The climate information presented above illustrates the predictable seasonal patterns in weather conditions and the obvious link between solar radiation and air temperature. That is, there is a greater incidence of solar radiation during the summer and autumn periods with a corresponding increase in air temperature. Vinall (2001) also demonstrated that during the summer and autumn periods, evaporation from Lake Hamilton clearly exceeds precipitation. However, there has been some degree of variation in rainfall in the region with an extended dry period from late 2004 through to late 2006. High rainfall periods have also been observed in both winter and summer months.

3.3 Physical Features and Hydrology

Lake Hamilton lies within the western district coastal plains and was constructed in 1977 following the construction of an embankment on the Grange Burn (see Figure 1-1). Basic morphological features of the Lake are displayed in Table 3-1. Overall, the Lake is generally shallow (1 – 3 m) with the deepest point (> 7 m) located near the embankment.

Table 3–1. Basic Morphological Characteristics of Lake Hamilton (Modified from Vinall 2001)

Morphological Parameter	Value
Surface Area	38 ha
Length	1.8 km
Width	152 – 304 m
Normal Minimum Depth	1.5 m
Maximum Depth	7.6 m
Small Island Surface Area	0.6 ha
Large Island Surface Area	2.0 ha

The embankment contains an outlet valve that is used to manage water levels as agreed on by Lake User Groups (RDC 2006). Historically, water has been released from the Lake for maintenance and flood control purposes, to control aquatic plant growth, and in the belief that nutrient rich water will be released (RDC 2006). No records are currently collected with regard to water levels in Lake Hamilton (pers. comm. Aaron Kennett – SGSC). Consequently, seasonal to changes in water levels of the Lake are not known.

Stream flow data of the Grange Burn upstream of the Lake is also limited; especially during the period that monitoring by the SGSC has occurred. This limits any inferences that can be made regarding the influence of stream flow on the ecological dynamics of the Lake. However, average daily flows indicate that a higher flow levels occur in the Grange Burn during the wetter periods of the year; particularly during August and September (Figure 3-3). Vinall (2001) calculated that flow from the Grange Burn has the capacity to fill the Lake 30 times in an average year. The absence of an over-flow out of the Lake during drier periods of the year also has the potential to lead to an accumulation of nutrients in the Lake (Vinall 2001).

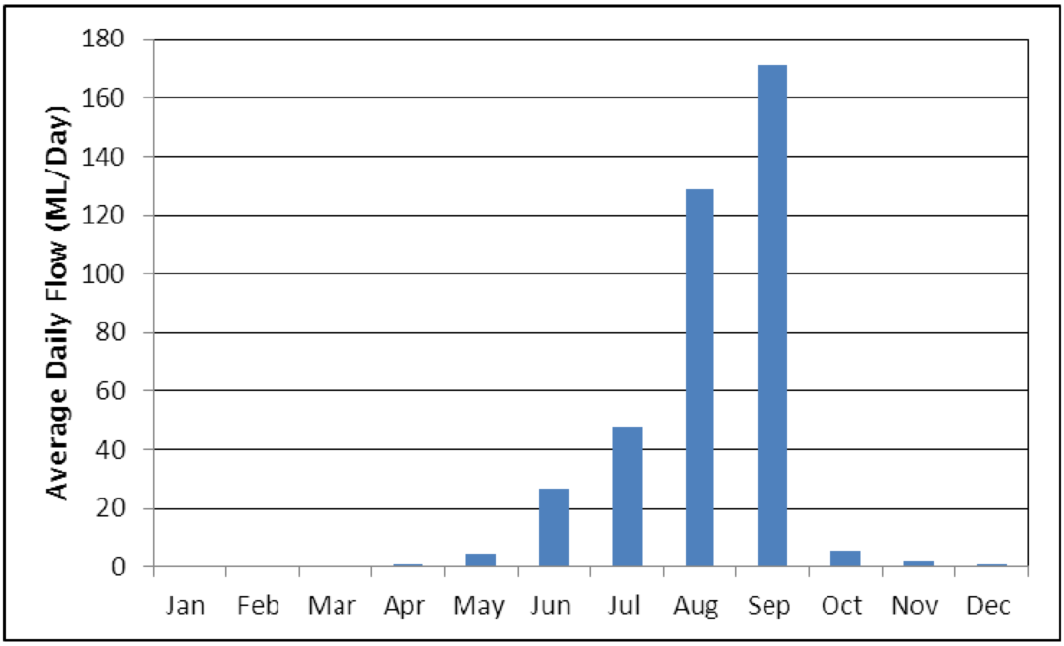


Figure 3-3. Mean daily flow of the Grange Burn at Robson's Road Hamilton (Gauge Number 238239)

Consideration should be given to potential downstream impacts on the Grange Burn if water releases are utilised in the future with the aim of managing nutrient loads and algal blooms in the Lake. The potential impacts may be more intense if Lake Hamilton undergoes periods of seasonal stratification with water released from the hypolimnion (see Section 3.4.1 for definition). Hypolimnetic or bottom water withdrawal has been used as a method to maintain water quality in European and North American lakes for decades (see Marshall *et. al.* 2002 for examples) and similar techniques are also employed in water storages throughout Australia (e.g. Reece 2004). Potential risks to the downstream environment include the release of cold water with low dissolved oxygen, high P, and potentially high levels of ammonia, hydrogen sulphide and metals (Marshall *et. al.* 2002; Reece 2004). Such impacts can pose a serious threat to the viability and survival of fish communities and other aquatic biota (Marshall *et. al.* 2002; Reece 2004). Aesthetic impacts such as nuisance odours may also occur.

There are a total of eleven stormwater drains that enter the Lake. The physical characteristics of each of the stormwater drains varies (see Plate 3), with seven piped inlets, a rock swale inlet at the northern end of the Lake, and two grass swale inlets on the northern and western banks. The rock and grass swales are generally aimed at removing sediment, hydrocarbons and nutrients (RDC 2006) although their effectiveness in doing so is not currently known. A settling pond (the Frog Pond) has also been constructed on the eastern bank to trap sediments and litter and to filter out other pollutants such as *E. coli* and nutrients. There is no discharge data available for the stormwater drains so an analysis of the influence of flow on pollutants cannot be made in this report.

Plate 3. Examples of stormwater drains to Lake Hamilton – piped inlet (left), grass swale (centre) and the Frog Settling Pond. The pipe and grass swale photos were sourced from The Regional Development Company (2006)

3.4 Physico-chemical and Nutrient Dynamics

Vinall (2001) conducted a preliminary assessment of the physio-chemical properties in Lake Hamilton in 1998-1999 that included observations of temperature, salinity, dissolved oxygen, pH and nutrients. This section uses a combination of information derived from Vinall (2001) and the SGSC monitoring program to describe the physico-chemical and nutrient dynamics of the Lake.

3.4.1 Thermal Stratification

The ecological dynamics of a temperate lake, such as the formation of algal blooms, are largely influenced by stratification patterns. A lake becomes thermally stratified when two distinct temperature layers form – a surface layer of warm water and a deeper colder layer (see EPA Victoria 2004). During spring the sun warms the surface layers of water. These warmer surface layers become less dense but are mixed with the cooler 'bottom' water by wave action. As heating continues during late spring and into summer, the temperature difference between the layers increases and wave action becomes less able to drive the mixing. When mixing ceases altogether, the warmer surface water lies over the cooler, dense bottom waters.

Once thermal stratification has occurred, the warmer upper layer is termed the epilimnion and the colder deeper layer is the hypolimnion. A sharp temperature gradient separating the two layers is the thermocline. Because the warm water is exposed to the sun during the day, a stable system exists, and very little mixing of warm and cold water occurs in calm weather. One result of this stability is that as summer progresses the oxygen below the thermocline is decreased. This occurs as organisms in the deeper water deplete the available oxygen through respiration or decomposition of organic material. Furthermore, as the water below the thermocline never circulates to the surface there is no chance of wind-mixing and re-supply of oxygen. The anoxic conditions in the hypolimnion can also facilitate the release of nutrients from sediments.

As winter approaches the temperature of the surface water decreases as cooling during the night dominates heat transfer. A point is reached where the density of the cooling surface water becomes greater than the density of the deep water and 'overturning' begins as the dense surface water moves down under the influence of gravity. Wind or other processes (e.g. currents) that agitates the water aids this process by bringing water to the surface. Although low in oxygen, the hypolimnion is higher in nutrients than the original surface water and this enriching of surface water nutrients may produce phytoplankton blooms.

Vinall (2001) found that there was little variation in temperature between the surface and deeper waters of Lake Hamilton and no evidence of stratification in oxygen (oxycline) or salinity (halocline). The lack of stratification in the Lake suggests that the high nutrients levels in the sediments (see Section 2.5) would remain bound to the sediments and not be released to the water column under anoxic conditions. However, Vinall (2001) made this conclusion based on limited data collected monthly from March 1998 to September 1999. There is anecdotal evidence to suggest that stratification may occur in the Lake (pers. comm. Stephen Ryan – Glenelg Hopkins Catchment Management Authority). Further monitoring for stratification during warm periods and possibly during extended hot weather conditions with little wind may detect the presence of a thermocline. This knowledge gap is required to be investigated more thoroughly to aid in the understanding of the Lake's dynamics and hence, the most appropriate management strategies.

3.4.2 Seasonal Changes in Nutrients

Vinall (2001) estimated the nutrient loads that are delivered to Lake Hamilton from the Grange Burn. During high winter flows, up to 7000 kg of N and 800 kg of P can enter the Lake per month (Vinall 2001). In summer and autumn these loads are smaller and in the range of <100 kg for N and < 10 kg for P (Vinall 2001). However, Vinall (2001) did not detect any major seasonal patterns in the nutrient levels of the Lake. There was also no distinct seasonal pattern evident in an examination of the SGSC monitoring program data. Consequently, it appears that the Lake is high in nutrients throughout each year. The OCE (1998) ratings applied by Vinall (2001) also suggest that the high nutrient content of the Lake results in it usually being classified as poor or degraded.

Despite the high nutrient loads delivered to the Lake from the Grange Burn and stormwater drains (see Section 2.3), the largest potential source of nutrients is the Lake sediments. Vinall (2001) calculated that around 4600 tonnes of N and 1300 tonnes of P are within the Lake sediments. The lack of any seasonal stratification may limit the availability of these nutrients – particularly P – to phytoplankton but this requires further investigation (see Section 3.4.1).

Regardless of whether the Lake stratifies or not, the high nutrient levels in the sediments may still influence the occurrence of algal blooms. This is because some Cyanobacteria (e.g. *Microcystis*) are able to strip nutrients from sediments (Vinall 2001) – predominately in shallow regions of a waterbody. Macrophytes and bacteria are also able to transfer nutrients from the sediments to the water column as they grow.

3.4.3 Biological Communities

3.4.3.1 Aquatic and Riparian Vegetation

There are significant stands of aquatic macrophytes in the littoral zone (shallow perimeter) surrounding the Lake (Plate 4). These macrophytes include taxa such as Cumbungi (*Typha* spp.), Common Reed (*Phragmites australis*), Water Ribbon (*Triglochin* spp.), Umbrella Sedges (*Cyperus* spp.) and Rushes (*Schoenoplectus* spp. and other species). Both native and exotic aquatic macrophytes are present in the Lake but there are no known natural occurrences of individual species or communities listed as threatened or endangered (RDC 2006).

Elevated nutrient loads, warm air temperatures and small to no water flow are thought to favour the development of macrophytes stands (RDC 2006; Vinall 2001). The growth of aquatic macrophytes in Lake Hamilton has led to recreational concerns due to restricted angler access and difficulties for the launching of boats (RDC 2006). There are some management options for controlling the spread of macrophytes although these options should be combined with reducing nutrient inputs from the Grange Burn and stormwater (RDC 2006) to prevent the formation of algal blooms. Both submerged and large emergent macrophytes are important in the consumption of nutrients from the waterbody and for nutrient transformations. They are also critically important as primary producers, and for the provision of habitat for aquatic fauna. Given the important role they play the macrophytes within the Lake should be maintained and even enhanced to increase their effectiveness as a 'sink' for nutrients. Removal of macrophytes on a large scale for purposes such as to increase recreational access can cause an imbalance of lake ecosystems, reduce nutrient consumption and compound the issue of algal blooms.

Plate 4. Example of aquatic macrophytes in the littoral zone (left), submerged algal mat (centre) and riparian vegetation (right) from Lake Hamilton

A significant mat of the filamentous green algae (possibly *Cladophora* sp) was also observed during the collection of sediment samples during December 2011 (Plate 4). In temperate areas, *Cladophora* is more abundant in the summer months and is a major algal problem in urban creeks and in enriched bays and oceans (Entwisle *et. al*. 1997). Floating scum of green algae, including *Cladophora*, is a common occurrence in nutrient-rich shallow pools or slow-flowing waterways. This further illustrates that eutrophication is a major characteristic of Lake Hamilton.

Lake Hamilton generally lies within the urban centre of Hamilton. Despite this, the Lake is surrounded by recreational parklands with some riparian vegetation (Plate 4). The majority of the riparian vegetation comprised of large native trees and regularly mown grass. The native vegetation within and surrounding the Lake has a high ecological value and provides significant habitat to birds, platypus and other aquatic fauna (RDC 2006). There is no data regarding the water quality of overland flow so the importance of the riparian zone in reducing nutrient inputs cannot be assessed.

3.4.3.2 Mammals and Birds

The Australian Platypus Conservancy has confirmed multiple sightings of platypus (*Ornithorhynchus anatinus*) in both Lake Hamilton and the Grange Burn and based on the volume of reported sightings the population is believed to be significant. Wallabies (Macropodidae) have also been observed around Lake Hamilton, particularly on the small islands within the Lake (pers. obs. Peter Lind).

In a lake ecosystem, aquatic macrophytes and riparian vegetation provide an important bird refuge. Lake Hamilton is no exception to this with a significant number of bird taxa benefitting from the Lake. The RDC (2006) suggests that the bird fauna includes Egrets, Crakes, Rails, Swamp Hens, Moorhens, Reed Warblers, Grassbirds, Ducks and Cormorants. Bird droppings are particularly rich in P, and excessive bird populations could cause nutrient enrichment of waterbodies. However, it is probable that bird droppings are just a minor factor involved in the water quality deterioration of the lake compared with nutrient inputs from other sources.

3.4.3.3 Fish and Macroinvertebrate Communities

Predatory fish species are stocked into Lake Hamilton by the Department of Primary Industries (DPI) to resource the recreational fishing community following a regional consultation process. Annually, the DPI stock around 3,000 Brown Trout (*Salmo trutta*) yearlings (RDC 2006). Rainbow Trout (*Oncorhynchus mykiss*) have also been stocked in the past and in 2000, around 1,000 Estuary Perch (*Macquaria colonorum*) were released as part of a stocking trial (RDC 2006). Other exotic fish species present include Redfin (*Perca fluviatilis*) and Mosquitofish (*Gambusia holbrooki*).

Currently there are no issues related to the occurrence of European Carp (*Cyprinus carpio*) in the Lake. There have been suggestions that carp may increase the likelihood of algal blooms by preying on animals that eat algae, stirring up nutrients trapped in bottom sediments, damaging aquatic plants, and reducing plant growth via an increase in turbidity (DPI 2012). Due to this, preventing Carp from colonising Lake Hamilton is a high priority into the future and any sightings in the Lake or Grange Burn should be reported to the SGSC and Glenelg Hopkins Catchment Management Authority immediately. There is currently no data relating to the composition and abundance of macroinvertebrate communities in Lake Hamilton.

3.4.3.4 Zooplankton Communities

Vinall (2001) conducted a preliminary assessment of the zooplankton community in Lake Hamilton during 1998-1999. Zooplankton are microscopic taxa (predominately Protozoans and Crustaceans) that move passively in a waterbody. Herbivorous zooplankton are strong grazers who consume phytoplankton including Cyanobacteria. They themselves are important in the food chains and food webs of balanced aquatic ecosystems and provide a crucial source of food to larger aquatic organisms such as fish.

In many situations the abundance of zooplankton is often determined by nutrient concentrations in the water column, the abundance of phytoplankton and fish populations. Zooplankton management has been proposed as a bio-manipulation method to manage algal communities using a ‘top-down’ manipulative approach. As such, an understanding of zooplankton communities in a lake is essential to understanding the processes leading to the formation of algal blooms.

The distribution of zooplankton communities can vary temporally (i.e. seasonally) as well as spatially (vertically and horizontally) within a lake. Seasonal changes in zooplankton may occur due to temperature as different taxa have a preferred temperature range that allows maximum growth and reproduction (Vinall 2001). Vertical migration may occur as herbivorous zooplankton follow algae that migrate up and down in the water quality in response to light and temperature (Vinall 2001). Horizontal migration of zooplankton can potentially be in response to the habitat provided by littoral macrophytes. Macrophytes in the littoral zone can provide shelter from predators and currents, as well as being the location of food sources such as epiphytes (Vinall 2001).

The dominant zooplankton taxa in Lake Hamilton were Cladocerans (*Daphnia* spp.) that are known to feed on Cyanobacteria (Mackey and Elser 1998; Claska and Gilbert 1998). Calanoid Copepods were another contributor to the zooplankton community although their abundance was not as high and varied overtime (Vinall 2001). The spatial distribution of *Daphnia* in the Lake was found to be highly heterogeneous and Vinall (2001) suggest that this was not influenced by either temperature or food sources. However, the seasonal cycles of *Daphnia* in the Lake generally followed that of phytoplankton and it was concluded that an increase in the phytoplankton food source triggered *Daphnia* to reproduce (Vinall 2001). Alternatively, as phytoplankton abundances declined there was a corresponding decline in the abundance of *Daphnia* (Vinall 2001). A lag effect of around one month was also observed between the changes in the phytoplankton and zooplankton communities (Vinall 2001).

Mackey and Elser (1998) suggest that, through a combination of grazing and nutrient recycling, *Daphnia* may be more efficient at reducing the incidence of Cyanobacterial blooms than in controlling and dissipating blooms that have already become established. Consequently, management of the Lake to favour zooplankton communities may also reduce Cyanobacterial blooms. For instance, *Daphnia* are potentially adversely affected by Cyanobacteria toxins and an increase in temperature has been found to significantly increase the sensitivity of *Daphnia pulex* to *Anabaena* toxins (Claska and Gilbert 1998). This highlights the importance of water temperature in the management of Cyanobacterial blooms. Although Vinall (2001) has pointed out the possibility of using zooplankton to control algal blooms using a 'top-down' approach, the bio-manipulation process is complex and for Lake Hamilton, it can only assumed to be beneficial. In contrast, alternate lake management solutions that combine control of nutrients entering a waterbody and nutrient reduction through consumption by macrophytes have a higher likelihood of success.

3.4.3.5 Phytoplankton Communities including Cyanobacteria

Algae are a primitive group of aquatic photosynthetic organisms. Many of the microscopic species are planktonic (free-floating or suspended in the water column). They are probably the most important organisms who keep the earth's oceans and freshwater productive (Reynolds 1984).

One group of planktonic algae is Cyanobacteria (or Blue Green Algae) which include unicellular, multi-cellular, filamentous and colonial forms. All planktonic Cyanobacteria are potentially bloom-forming although only a few taxa including *Microcystis* spp., *Nostocales* spp., *Anabaena circinalis* and *Oscillatoria* spp.contain species which are regarded as detrimental to Australian water supplies (Cullen *et. al.* 1993). In addition to planktonic forms, Cyanobacteria can flourish as benthic populations on rocks (epilithic), plants (epiphytic), or lake bottoms (epipelic). *Oscillatoria* is a common epipelic species inhabiting Australian lakes and reservoirs.

Cyanobacterial growth is dependent on a combination of the following conditions (Reynolds 1984; Cullen *et. al.* 1993; Chorus and Bartram 1999):

- Light;
- Phosphorus and nitrogen;
- A ratio of N:P < 16;
- Water temperature (mostly range 15-25°C or slightly above; long, sunny days);
- Calm conditions and water column stability;
- Trace elements (mainly iron);
- Water pH (slightly alkaline, > 8.0);
- A readily available source of organic carbon;
- Dissolved carbon dioxide; and
- Low turbidity.

Different species of Cyanobacteria require different conditions to bloom. However, blooms often occur in warm, calm, shallow water bodies that receive elevated nutrient loads (Smith 1983; Pick and Lean 1987; BGATF 1992; Cullen *et. al.* 1993; Chorus and Bartram 1999). When water is mixed by wind or by mechanical aeration, the potential for bloom formation is reduced. This is because mixing breaks up the stratification and reduces the amount of time algae spend at the surface where they have access to light. Flowing water can also flush algae away before they amass into a bloom.

The majority of the conditions that favour Cyanobacteria growth listed above are part of the Lake Hamilton ecosystem. Vinall (2001) found that although the spatial distribution of algae was relatively homogeneous, increases in temperature and light during the warmer periods of the year were correlated with an increase in phytoplankton abundance. However, different taxa dominated the blooms and this may indicate that different triggers may have initiated the blooms in different years (Vinall, 2001).

3.4.3.6 Biological Interactions – Control of Cyanobacteria

In a 'healthy' lake ecosystem there should be representative fauna in all trophic levels in a food chain. If one of the trophic levels is absent or rare, direct and indirect impacts can occur in other trophic levels. For example, an absence of large predatory (piscivorous) fish would lead to an increase in the numbers of smaller planktivorous fish that prey on zooplankton. As a result of this, the numbers of zooplankton would decrease as they would be consumed more as a food item. This could lead to a decrease in herbivorous zooplankton, which consumes phytoplankton, resulting in an increase in algal abundances.

In the theoretical case of Lake Hamilton, some level of control of the algal blooms could be achieved, in part, by maintaining a large zooplankton community to continually graze on the algae. Vinall (2001) observed a healthy zooplankton community in the Lake and that the abundance of zooplankton was closely linked to that of the algae. Consequently, it does appear that there is grazing pressure on the algae from the zooplankton. Due to this, it is important to maintain the current food chain dynamics in the Lake. In theory, the stocking of large predatory fish by the DPI (see Section 3.4.3.3) may be aiding in maintaining a large zooplankton community by feeding on smaller planktivorous fish. However, this is only speculative as there is little information fish communities in Lake Hamilton and their contribution to the maintenance of all trophic levels is unknown.

4 Risk Assessment

In the Australian water industry, the assessment of risks and subsequent management actions based on the identified risks are increasingly being used as a means of assuring the quality of drinking water and water for other uses (such as the environmental or recreational users). The AS/NZS 4360: Risk Assessment approach provides a framework for the identification, analysis, assessment, treatment and monitoring of risk arising from any activity (see AS/NZS 1999). In this context risk is broadly defined as *"….the chance of something happening that will have an impact upon objectives….*"

The key steps in this approach are to:

- Establish the context, or understand the system and what is monitored;
- Identify risks, primarily by considering what could happen;
- Determine and rank risks, by considering likelihood and consequence; and,
- Management of risks or controls at the source of risk and the target.

The standard risk assessment approach considers the likelihood of occurrence of an event and its potential environmental and/or public health impacts. The risks associated with Lake Hamilton were identified based on the water quality-related issues considered in Section 2.0 and 3.0 above.

4.1 Water Quality Risk Assessment Process

The water quality Risk Assessment process uses the approach outlined in AS/NZS (1999). This involved a consideration of each component of Lake Hamilton including inputs from the Grange Burn and the stormwater drains and seasonal variation. This assessment contains several key elements:

- Identification of the potential water quality issues through review of the water quality data, system understanding, and discussions with SGSC staff and other stakeholders;
- Identification of potential sources and causes of the water quality issues;
- Assessment of the likelihood, severity and risk associated with each issue to obtain a risk rating; and,
- Determination of the preventative or remedial options for each issue.

The likelihood, severity and risk of each hazard were assessed based on the agreed criteria and risk matrix contained in Tables 4-1 to 4-3 below. These criteria are found in AS/NZS (1999) and NHMRC (2004).

Table 4-1. Likelihood Scale

Level	Label	Probability/Frequency
1	Rare	The event may occur only in exceptional circumstances; such as once in 100 years
2	Unlikely	The event could occur at some time; once in 50 years
3	Possible	The event should occur at some time; once in 5 to 10 years
4	Likely	The event will probably occur in most circumstances; annually
5	Almost certain	The event is expected to occur in most circumstances; several times a year to monthly

Table 4-2. Consequence Severity Scale

Level	Label	Description
1	Insignificant	Insignificant impact
2	Minor	Minor impact for a small population
3	Moderate	Minor impact for a large population
4	Major	Major impact for a small population
5	Catastrophic	Major impact for a large population

Notes.

1. *Minor impact refers to aesthetic water quality impacts only. A major impact refers to any health water quality impact.*
2. *Small population is <100 people. Large population is >100 people.*

Table 4-3. Risk Matrix

Likelihood	Consequence				
	1 (Insignifican	2 (Minor)	3 (Moderate)	4 (Major)	5 (Catastrophic)
1 (Rare)	Low	Low	Medium	High	High
2 (Unlikely)	Low	Low	Medium	High	Very High
3 (Possible)	Low	Medium	High	Very High	Very High
4 (Likely)	Medium	High	High	Very High	Very High
5 (Almost certain)	Medium	High	Very High	Very High	Very High

4.2 Key Issues and Risks Considered

In the context of Lake Hamilton, the identification of risks to manage water quality and prevent Cyanobacterial blooms requires a consideration of the physical features of the Lake, physico-chemical parameters and nutrient levels, sediment quality, biological communities and spatial and temporal variation in all components. These components have been addressed in Sections 2 and 3 above. Consideration should also be directed at potential impacts on wildlife which currently inhabit the water body (i.e. turtles and eels - both of which are threatened), and potential exposure of stakeholders to hazardous material (of biological or chemical origin) in the waterbody. The above issues and components were considered in the Risk Assessment below (see Table 4-4).

From the risk assessment the highest risks were posed by the following:

- Elevated nutrients entering to the Lake from the Grange Burn and stormwater drains;
- Elevated nutrient levels in the water column and sediments that have the potential to lead to the formation of Cyanobacterial blooms;
- Continued eutrophication of the Lake, increasing the risks of recurrent Cyanobacterial blooms; and,
- Cyanobacterial blooms, which are toxic or potentially toxic, that could cause significant hazards to user groups.

Several lower level risks were also identified. They are related to the following:

- Occasional contamination by microbial pathogens (*E. coli*) at levels potentially harmful to user groups;
- Potential of stratification in the water column leading to a release of nutrients from the sediments;
- Low water temperatures that are potentially harmful to user groups; and,
- High pH levels that is favourable to the formation of Cyanobacteria.

Table 4-4. Water quality Risk Assessment of Lake Hamilton and potential remedial or control measures

RAW RISK					CURRENT RISK		
Risk	**Likelihood of Risk**	**Consequence of Risk**	**Risk Level**	**Remediation or Control Measures**	**Likelihood of Risk after Controls**	**Consequence of Risk with Controls**	**Residual Risk**
Water Quality – Water quality poor due to high pH levels.	5 – Monitoring indicates pH >8.3 regularly from Dec 2009 to Aug 2010.	2 – Slightly elevated pH benefits Cyanobacteria blooms. However, high nutrients are the dominant influence. Lack of rain may also have contributed to high pH.	High	**Monitoring** • Continue monitoring of Lake Hamilton pH. **Risk Remediation** • Manipulation of pH regularly occurs in water treatment facilities but is highly complex for natural lake ecosystems (e.g. lime/acid dosing to increase/decrease pH). • Implementation of nutrient management is of more importance than pH levels. Risks of elevated pH may be mitigated through nutrient management.	3 – High pH potentially due to natural seasonal variation.	2 – May contribute to Cyanobacterial blooms in a small way but nutrient management more important & feasible.	Medium
Water Quality – Water quality poor due to high electrical conductivity levels.	5 – Monitoring indicates EC regularly >1500 µS/cm.	1 – Western Vic. flora & fauna adapted to high levels. Little impact on lake user groups at levels recorded.	Medium	**Monitoring** • Continue monitoring of Lake Hamilton electrical conductivity. **Risk Remediation** • Decreases in saline intrusion to the Grange Burn & Lake Hamilton may occur, in part, through remedial measures aimed at control nutrient inputs from the catchment (e.g. establishment of native vegetation).	4 – Saline groundwater in region a natural occurrence that will be ongoing.	1 – Little direct or indirect impacts on lake user groups anticipated.	Medium

Water Quality – Water quality poor due to low water temperatures.	5 – Monitoring indicates water temp. <15°C several times a year.	2 – Only small number of user groups exposed to low water temp.	High	**Monitoring** • Continue monitoring of Lake Hamilton water temperature. **Risk Remediation** • A 'common sense' approach to be used by user groups to use suitable clothing and avoid prolonged exposure. • SGSC to include the potential risk of cold water & to recommend use of appropriate clothing on signage around Lake.	5 – Low water temperatures are natural & will be ongoing.	1 – User groups not expected to be overly impacted.	Medium
Water Quality – Nutrients from catchment discharging into Lake leading to algal blooms.	5 – Monitoring indicates excessive nutrients entering Lake from Grange Burn & stormwater. N:P ratios regularly favour Cyanobacteria.	4 – Potential health risks for Lake user groups. Loss of environmental, social & economic value to region.	Very High	**Monitoring** • Continue monitoring of Grange Burn, stormwater drains & Lake Hamilton nutrients. • Establish the basis for on-going intervention and remediation. **Risk Remediation - Nutrient Reduction** • Reduce entry of algal growth nutrients (esp. TP & TN) into the Lake from the Grange Burn, stormwater drains & overland flow. • Implement large-scale catchment management upstream to decrease nutrient supply from Grange Burn (e.g. revegetation, riparian buffer strips, preventing stock access to waterways). • Educate the community about impacts of stormwater inputs on Lake health. • Investigate potential of stormwater treatment swales to reduce nutrients levels in stormwater. • Investigate potential of treatment wetland upstream of the Lake on the Grange Burn to reduce nutrient levels entering the Lake. • Improve riparian buffer zones around the Lake to reduce entry of nutrients into pond via overland flows.	4 – Large-scale nutrient management actions may not reduce nutrient levels in the immediate future but may take a few years.	2 – Eventually, risks to user groups will be reduced overtime.	High

Microbial Pathogens – Water quality poor due to high levels of microbial pathogens (*E. coli*).	3 – Monitoring indicates excessive *E. coli* levels once in past five years.	2 – No impacts on secondary users. Primary users such as swimmers & water skiers at risk on only one occasion.	Medium	**Monitoring** • Continue monitoring *E. coli* in Grange Burn, stormwater drains & Lake Hamilton. • Investigate potential of using microbial source tracking (MST) to identify sources of *E. coli*. In the Grange Burn & stormwater drains. **Risk Remediation** • Reduce entry of microbial pathogens into the water body from stormwater & Grange Burn. • Implement stock exclusion measures on the Grange Burn to reduce faecal inputs (i.e. fencing). • Undertake rehabilitation of riparian zones along Grange Burn. • Educate community about impacts and causes of *E. coli* in stormwater. • Inform Lake user groups of risks from high *E. coli* levels on signage around Lake.	2 – Anticipated that *E. coli* levels will be reduced in the Lake overtime.	2 – Still potential impacts in near future. Potential may increase with further urbanisation in Hamilton or greater stocking of agricultural areas upstream.	Low

Nutrients in Sediments – Water quality poor due to high levels of nutrients being released from sediments.	4 – Although no evidence of stratification in Lake, it is assumed that nutrients are released during the warmer seasons each year.	4 – The released nutrients potentially contribute to algal blooms.	Very High	**Monitoring** • Conduct occasional sediment monitoring to document levels of nutrients. • Conduct investigation of stratification in the Lake. Currently only anecdotal evidence of stratification. **Risk Remediation** • Establish and/or protect submerged, aquatic vegetation to consume some nutrients & stabilise sediments. • Investigate potential of dredging sediments to remove nutrients. • Investigate potential of artificial aeration if evidence of stratification is found in the future.	3 – Should nutrient levels be decreased they would again accumulate overtime. Large-scale nutrient management actions may not reduce nutrient levels in the immediate future but may take many years.	2 – Eventually, risks to user groups will be reduced overtime.	Medium

Cyanobacterial Blooms – Water quality poor due to blooms in the water	5 – Monitoring indicates toxic Cyanobacterial biovolumes >4mm³/L during warmer periods of the year.	4 – Potential health risks & loss of environmental, social & economic asset.	Very High	**Monitoring** • Continue monitoring of Cyanobacteria in the Lake. • Assess 'site-specific' conditions that lead to bloom formation (done in part in this report). • Assess Cyanobacterial composition & biovolumes to determine presence/absence of toxic species. • Occasionally determine Cyanobacterial toxicity levels in water. **Risk Remediation – Short-term** • Install signage at highly visible areas around Lake to warn user groups of Cyanobacterial risks; maintain signage until bloom disappears. • Use media releases to inform the public of Cyanobacterial risks. • Time large-scale recreational activities such as rowing regattas to be in the colder periods of each year. **Risk Remediation – Long-term** • Undertake catchment management actions to reduce nutrient loads entering the Lake from the Grange Burn & stormwater (see nutrient reduction above). Generally, these large scale rehabilitation actions may take a few years to be effective. • Maintain & increase aquatic macrophytes in the Lake, both submerged & emergent species, to provide better habitat conditions (i.e. increased dissolved oxygen) & to consume nutrients.	4 – Short-term remediation prevents exposure to Cyanobacterial risks. Long-term & large-scale remediation may not reduce blooms in the immediate future but may take many years.	3 – Potential health risks & loss of environmental, social & economic asset will remain until long-term actions become effective.	High

Cyanobacterial Blooms – Ecosystem unbalanced due to absence of trophic groups.	2 – All trophic groups represented in the Lake. Some chance of large scale mortalities if Cyanobacterial blooms severe or water quality deteriorates.	2 – Potential for increases in algae if trophic balance disrupted.	Low	**Monitoring** • Records of stocking rates to be kept. • Monitor for the presence of European Carp. **Risk Remediation** • Maintain stocking program of large predatory fish. • Eliminate European Carp if observed in the future.	2 – Unlikely of trophic group loss if Best Management Practices utilised.	2 – Still potential impacts in near future.	Low

5 Conclusions and Recommended Management Options

The review of the SGSC monitoring program and the ecological dynamics of Lake Hamilton indicate that the Lake has undergone long-term eutrophication. Eutrophication is defined as an enrichment or waterways and waterbodies by nutrients and the enhancement of productivity and respiration (Strumm and Morgan 1970). Although eutrophication is a natural ageing process of lakes and reservoirs, catchment impacts such as land clearing, the application of fertilizers like superphosphate, stock access to waterways and stormwater inputs increases the rate at which eutrophication occurs. This can have detrimental effects such as an increase in the formation of Cyanobacterial blooms.

The major issue with Lake Hamilton was found to be high levels of nutrients in the water column and sediments (especially nitrogen and phosphorus). The main sources of the nutrients were from both stormwater drains and the Grange Burn. Consequently, both these sources of water to the Lake will require remedial management actions to limit the recurrence of Cyanobacterial blooms. The large pool of nutrients in the sediments of the Lake may not be as much of a concern, particularly as there is no evidence of stratification. However, more investigation of the impacts of the sediment nutrients and stratification patterns should be carried out as there is some anecdotal evidence that stratification does exist (pers. comm. Stephen Ryan – Glenelg Hopkins Catchment Management Authority). Furthermore, regardless of whether the Lake stratifies or not, the high nutrient levels in the sediments may still influence the occurrence of algal blooms as some Cyanobacteria (e.g. *Microcystis*) are able to strip nutrients from sediments (Vinall 2001) and macrophytes and other bacteria are also able to transfer nutrients from the sediments to the water column as they grow. Despite this, ALS highly recommends that remedial management options should concentrate on limiting the supply of nutrients from the Grange Burn and stormwater drains (discussed further below).

5.1 Remedial Management Options

As part of the management of Lake Hamilton the water quality monitoring program conducted by the SGSC should be continued along with informing the community of water quality risks using signage, information brochures and media releases. Based on a review of the SGSC monitoring program and other available information, the recommended remedial management options to address the water quality issues in Lake Hamilton are discussed below.

5.1.1 Long-term Remedial Management Options

Long-term remedial management options are generally implemented over a large area and typically include catchment management upstream of the waterbody. These solutions, discussed below, may take several years until they become totally effective. However, they represent 'best practices' and an 'ecosystem management approach' and are strongly recommended for consideration. The long-term options are aimed at reducing the supply of nutrients to the Lake from the catchment as a means of reducing the rate of on-going eutrophication and limiting the occurrence of algal blooms. The recommended long-term remedial actions for management identified in this investigation are:

- Construction of stormwater treatment swales;
- Construction of Grange Burn treatment wetland;
- Maintain, protect and even enhance aquatic macrophytes in the Lake; and,
- Prevention of nutrient inputs to the Lake through large scale catchment management (i.e. fencing and stock exclusion, improvement of riparian zones).

Stormwater treatment swales are generally linear depression of channels that provide for stormwater collection and conveyance. The swales may simply be grass-lined areas or more densely vegetated. The swales have the potential to provide for the capture of stormwater and the screening or removal of gross pollutants. Adequately designed swales also have the potential to remove nutrients from stormwater (see Appendix A).

Treatment wetlands are a series of distinct ‘cells’ that are designed to filter particles and other pollutants from water. The wetlands are designed and constructed so as to reduce the velocity of incoming waters to such an extent that sediments and pollutants can be removed. Natural filtering mechanisms such as vegetation are employed in the wetland to retain pollutants, thereby treating the water prior to them entering the Lake (see Appendix A).

The design of treatment swales and wetlands is a complex task requiring background information on the targeted system and the desired level of treatment. Some of the key steps in the design of swales and wetlands are discussed in Section 6.

The use of dredging has also been considered as a potential remedial option aimed at reducing the nutrient content in the sediments. However, as highlighted by Vinall (2001), it is an invasive and destructive technique that can lead to a loss of aquatic macrophytes and disruption of the natural trophic balance in the Lake. In the short-term, dredging can lead to the release of nutrients from the sediment that can compound existing algal blooms. Destruction of aquatic habitat and macrophytes within the Lake would also occur as a result of dredging. The loss of macrophytes may also compound existing algal blooms as they are a ‘sink’ for nutrients within the Lake and should be protected. A large financial investment is also required to implement a dredging program and ALS believes that the required funds would be better allocated to other remedial options.

Ultimately, the occurrence of Cyanobacterial blooms in Lake Hamilton could be reduced by controlling nutrient inputs from the Grange Burn using catchment scale management actions. These include the fencing of waterways to prevent stock access and establishment of strong riparian zones to form a buffer strip to filter nutrients and other pollutants.

5.1.2 Short to Medium-term Remedial Management Options

Short to medium-term remedial management options are generally aimed at eliminating an algal bloom after it has occurred or just prior to Lake conditions being favourable for bloom development. The potential short to medium-term remedial actions for management identified in this investigation are:

- Use of microorganisms to strip nutrients from water column and out-compete algal populations (e.g. products from EM Solutions Australia);
- Use of chemical controls (e.g. algicides or dyes) to eliminate algal populations;
- Use of chemical controls (e.g. EC-504 Algal Eliminator) to strip nutrients from the water column and sediments; and,
- Use of artificial aeration to break-down stratification and prevent release of nutrients from sediments.

Although highlighted in this report as potential remedial management options, the use of chemical control agents to address the water quality issues in Lake Hamilton are not recommended for a number of reasons. Firstly, Lake Hamilton is considered a natural waterbody that is an open system (i.e. flows further downstream into the Grange Burn). The use of chemical controls is usually only endorsed by the EPA in closed systems where other management options have been trialled and have either failed or been exhausted (pers. comm. Dave Robinson – EPA Victoria; Vinall 2001).

Chemical treatments are also usually used in small ponds or dams. Due to the relatively larger size of Lake Hamilton the amount of chemicals or dyes required can lead to huge financial costs. Vinall (2001) calculated that a single dose of dye aimed at reducing light penetration into the Lake would cost around $30,000 in today's money. Vinall (2001) suggested that multiple doses would be required within a year. Furthermore, the use of dyes is not aesthetically pleasing in that the natural clear water of the Lake would be turned a darker colour. Another chemical control is EC-504 Algal Eliminator that out-competes algae by stripping nitrogen from the water column and sediments. Based on manufactures specifications, around 2.4 tonnes would be required to treat Lake Hamilton over a three month period. Large amounts of other products such as microorganisms supplied by EM Solutions Australia would also be required and are not considered feasible for Lake Hamilton (pers. comm. Shane Raymond – EM Solutions Australia).

The large amounts of chemicals required to treat lakes such as Lake Hamilton often results in ANZECC and SEPP water quality guidelines being exceeded. The guidelines have been developed for the protection of aquatic ecosystems and adverse conditions can occur due to the input of toxicants in the form of chemical controls (pers. comm. Dave Robinson – EPA Victoria). The concentrations required are also often many times greater than that required to kill fish (pers. comm. Dave Robinson – EPA Victoria).

Toxins associated with Cyanobacteria can also be released after the algae have been destroyed. Consequently, the water may remain unsafe for months following the application of chemicals (Vinall 2001). Chemical control will also impact on all algal taxa and not just Cyanobacteria. This may potentially have implications on the trophic structure and functioning of the Lake and lead to further ecological impacts.

Vinall (2001) also suggests that even if nutrients are chemically or biochemically stripped from the Lake over summer, they are replaced every year by inputs from the Grange Burn. This further emphasises the need for large-scale nutrient management in the Grange Burn catchment.

The use of artificial aeration in Lake Hamilton to achieve better mixing, increase levels of dissolved oxygen, break down stratification (if it occurs) and prevent the release of nutrients from the sediment may help to limit the development of algal blooms. However, this is dependent on the occurrence of seasonal stratification of which there is currently no evidence. The use of aeration should be considered should stratification be detected in future monitoring.

6 Design of Treatment Wetlands and Stormwater Swales

The design of treatment wetlands and swales is a complex task and initially requires an understanding of the system that is targeted for rehabilitation (as determined in this report for Lake Hamilton). Information on the targeted system (e.g. local climatic conditions and water quality) is entered into specific software packages such as MUSIC.

Before proceeding further, it is important to note that using the MUSIC software is only the first step in the design of treatment options. MUSIC is used to identify the physical attributes of a treatment option that is required to reduce contaminants in waterways (e.g. recommendations are made with regard to the required size to accomplish a desired level of treatment). The physical attributes identified in MUSIC are subsequently used by suitably qualified hydrologists, design engineers, etc to establish the final design.

MUSIC (Model for Urban Stormwater Improvement Conceptualisation) was developed and enhanced by the eWater Cooperative Research Centre. The model allows users to simulate the quantity and quality (including nutrients) of runoff coming from catchments. The effect of a range of treatment options (e.g. wetlands or swales with different sizes and vegetation coverage) on the quantity and quality of the runoff is then assessed and a preferred option or combination of treatment options selected.

Essentially, MUSIC assists users to develop a range of treatment options that can be used to reduce nitrogen, phosphorus, suspended solids and gross pollutants in the runoff. To illustrate how MUSIC can be used to identify the most appropriate treatment options, consider a hypothetical example of stormwater with high levels of pollutants discharging into a lake. Initially, a range of treatment options to potentially reduce pollutants coming from the stormwater are identified by MUSIC (Table 6-1).

Table 6–1. Potential treatment options to reduce pollutant levels in stormwater

Hazard	Potential Management Options
Poor stormwater quality due to high nutrients	Bioretention swales Swales and buffer strips Bioretention basins On-site infiltration measures Sediment basins Constructed wetlands Water sensitive landscaping practices / rain gardens / planter boxes

A conceptual model of the treatment system is then developed with nodes representing each major component (Figure 6-1). In this example, sources of stormwater are urban car parks, buildings and roadways in the catchment. Initially, a buffer strip has been proposed to treat the car park runoff and a treatment swale to treat the building and road runoff. Once all water sources combine further downstream, an additional treatment swale and wetland have been proposed prior to the water discharging into the lake (the receiving node).

Underlying algorithms associated with each node model the effectiveness of each treatment option in reducing pollutants. Their effectiveness is assessed by adjusting their individual characteristics (e.g. size, vegetation coverage) and determining their potential to reduce pollutants as well as associated costs using before and after treatment scenarios. An example of costs associated with wetland and swales of two different sizes are presented in Table 6-2.

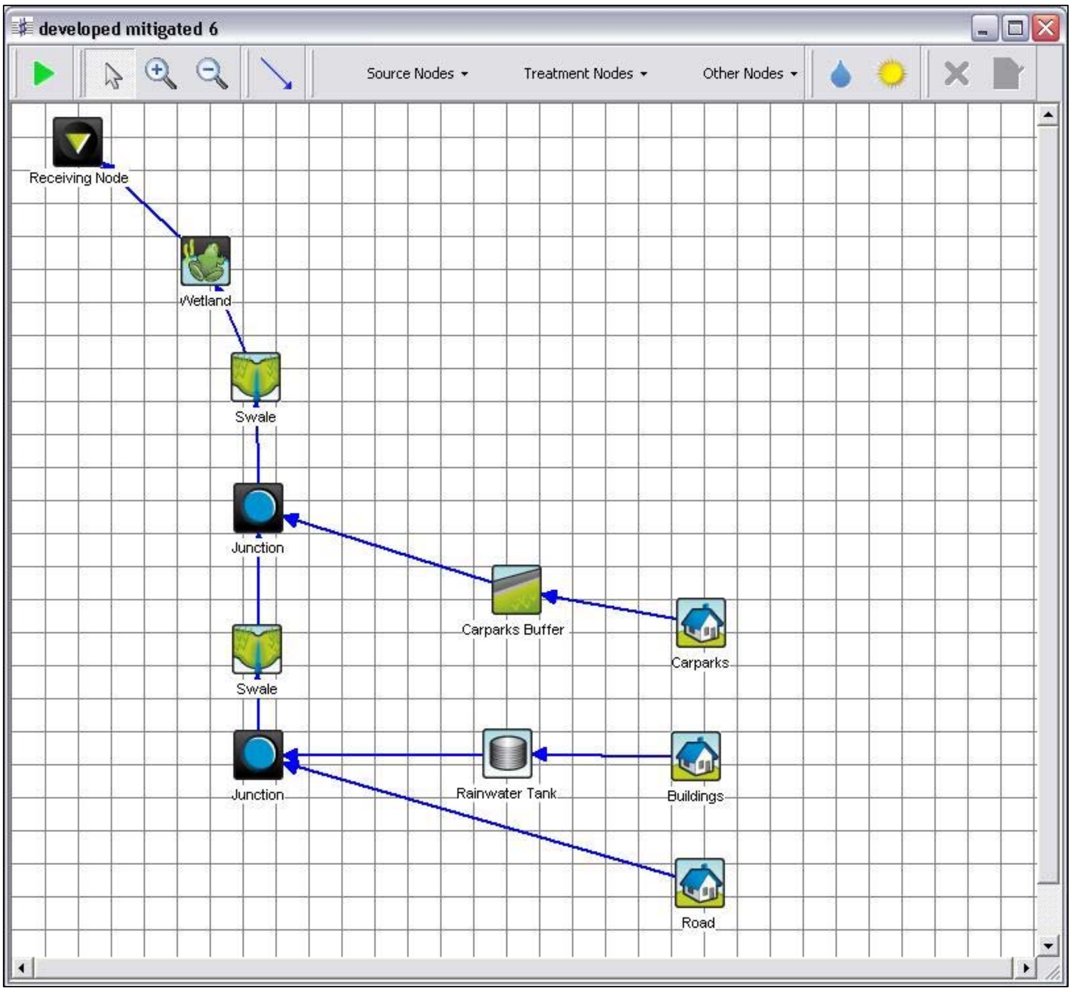


Figure 6-1. Hypothetical MUSIC model aimed at reducing pollutants in stormwater being discharged into a lake.

Table 6-2. Examples of whole of life cycle costs for some treatment options.

Treatment Type	Wetland		Swale	
Size	**200 m³**	**400 m³**	**150 m**	**300 m**
Life Cycle (years)	50	50	50	50
Acquisition Cost of Land	$73,463	$107,204	$50,354	$85,707
Annual Maintenance Cost	$887	$1,473	$6,389	$8,078
Renewal/Adaptation Cost	$8,366	$12,208	$27,130	$46,178
Renewal Period (years)	20	20	25	25
Decommissioning Cost	$34,374	$50,162	$21,699	$36,933
Real Discount Rate (%)	5.5	5.5	5.5	5.5
Annual Inflation Rate (%)	2	2	2	2
Life Cycle Cost ($2012)	$94,762	$141,304	$166,786	$236,720

In the case of Lake Hamilton, an overview of methodology that is likely to apply to design an appropriate treatment system is as follows:

- Consult and inform Advisory Committees and community explaining reasons behind the selected option/s;
- Gather appropriate site data regarding soils, land slope, covered areas, existing stormwater infrastructure and water courses;
- Source input data for MUSIC including appropriate rainfall data for Hamilton or nearest rainfall gauge to Lake Hamilton (preferably 6 minute or hourly data if available);
- Using MUSIC, investigate a range of treatment options that are appropriate for the site and that also achieve appropriate nutrient and gross pollutant reduction (the most likely options include constructed wetlands and swales);
- Present these options as a draft Conceptual Design Plan. This plan would include indicative costs (including construction, maintenance, renewal and decommissioning costs over the life of the asset) for each of the options;
- Southern Grampians Shire Council to potentially release the draft plan for community consultation;
- Southern Grampians Shire Council to provide feedback on the draft plan and a preferred option selected;
- The preferred option and design details identified in MUSIC to be incorporated into a detailed design and construction tender;
- Suitably qualified hydrological engineers (for example) to incorporate the design details and specifications identified in MUSIC into the design and construction of the treatment options.

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APPENDIX A – Results of a literature review investigating the capacity of treatment wetlands, swales, buffer strips, etc to remove nutrients from water

Table A1: Summary table for nitrogen removal

BMP	Reference study	Study location	Buffer vegetation	Buffer width (m)	Nitrogen removal (%)	Nitrate removal (%)	Study method
Riparian buffer Wooded vegetation	Merriman (Merriman, Gitau et al. 2006)	Arkansas, USA	Forest	-	37	48	Single study.
Riparian buffer Wooded vegetation	Makin (Makin, Ngandu et al. 2007)	-	Plumb shrub and native grass mix	8.3-16.1	44.4	-	9 plots with differing vegetation mixes, average results although vegetation mix did alter efficacy.
Riparian buffer Wooded vegetation	Kruijne (cited in (Hefting, Beltman et al. 2005)	-	Forest	10	-	28	Modeled.
Riparian buffer Wooded vegetation	Hefting (Hefting, Beltman et al. 2005)	Hazelbekke Stream, Netherlands	Alder and nettle	>20m	-	38	Environmental conditions.
Riparian buffer Wooded	Hefting (Hefting, Clement et al. 2005)	Netherlands France Switzerland Romania Spain	Forest	18 20 5 12 8	24.5 17.0 16.1 82.7 99.6	-	Natural conditions.
Riparian buffer Grassed	Hefting (Hefting, Beltman et al. 2005)	Ribet Stream, Netherlands	Reedgrass and nettle	>20m	-	63	Environmental conditions.
Riparian buffer Grassed	Hefting (Hefting, Clement et al. 2005)	Netherlands Netherlands France Switzerland Romania	Grass Grass mowed Grass Grass mowed Grass	20 20 20 15 12	12.6 29.7 17.5 31.0 73.0	-	Natural conditions.

BMP	Reference study	Study location	Buffer vegetation	Buffer width (m)	Nitrogen removal (%)	Nitrate removal (%)	Study method
Riparian buffer	Merriman (Merriman, Gitau et al. 2006)	Arkansas, USA	Vegetative buffer strip	- 3-8% slope 8-15% slope 4.6 3-8% 8-15% 15-25% 6.1 3-8% 9.1 3-8% 8-15% 15-25%	- 37 64 84 73 58 37 45 87 66	- 38-73 34 74 57 -6 48 37 79 4	Few studies.
Fencing (grassed buffer indicative)	Galeone (Galeone 2000)	Pennsylvania, USA	Grass	3-4	20	-	Fenced exclusion (leading to grassed buffer): 20% total nitrogen reduction through nitrate reduction (low flow).
Fencing (grassed buffer indicative)	Merriman (Merriman, Gitau et al. 2006)	Arkansas, USA	Grass	-	-78 (negative)	33	8-15% slope. Based on 1 study.
Alternate water and shade	Merriman (Merriman, Gitau et al. 2006)	Arkansas, USA	Grass	-	-27 (negative)	41	8-15% slope. Based on 2 studies.
Alternate water and shade	NC Dep. Env. Nat Res. (North Carolina Department of Environment and Natural Resources 2009)	North Carolina, USA	-	~30	16	-	Reduction based on 51% less time in the water although studies have shown up to 94% removal can be achieved.

BMP	Reference study	Study location	Buffer vegetation	Buffer width (m)	Nitrogen removal (%)	Nitrate removal (%)	Study method
Contour swale (indicative)	Charles (Charles, Davies et al. 2008)	NSW, Australia	Grass, but results are for sub-surface removal and application	1(clay loam) 10(clay loam) 20(clay loam) 1(loam) 5(loam) 20(loam)	~63 ~85 ~99 ~74 ~88 ~94	-	Natural and simulated rainfall conditions for a field site. Study challenges were distributed from an absorption trench, which may be likened to the biomat experienced in a contour swale / soil interface.
Swale	NRC summary (National Research Council 2000)	-	-	-	-	38	-
Contour	Merriman (Merriman, Gitau et al. 2006)	Arkansas, USA	-	3 3-8% slope 4.5 03% slope 3-8% slope	- 20 20	- 10 39 39	Based on 3 studies.
Wet pond	NRC summary (National Research Council 2000)	-	-	-	31	24	-
Constructed wetland	NRC summary (National Research Council 2000)	-	-	-	21	67	-

Table A2: Summary table for phosphorus removal

BMP	Reference study	Study location	Buffer vegetation	Buffer width (m)	Phosphorus removal (%)	Orthophosphorus removal (%)	Study method
Riparian buffer Wooded vegetation	Peterjohn (Peterjohn and Correll 1984)	Maryland, USA	Native hardwood	164	81	-	Surface and groundwater flow considered.
Riparian buffer Wooded vegetation	Lowrance (Lowrance, Todd et al. 1983)	Georgia, USA	Native hardwood	66-131	23	-	Based on subsurface floe only.
Riparian buffer Wooded vegetation	Merriman (Merriman, Gitau et al. 2006)	Arkansas, USA	Forest	-	56	-	Single study.
Riparian buffer Wooded vegetation	Makin (Makin, Ngandu et al. 2007)	-	Plumb shrub and native grass mix	8.3-16.1	42.9	-	9 plots with differing vegetation mixes, average results although vegetation mix did alter efficacy.
Riparian buffer	Merriman (Merriman, Gitau et al. 2006)	Arkansas, USA	Vegetative buffer strip	- 3-8% slope 8-15% slope 4.6 3-8% 8-15% 15-25% 6.1 3-8% 9.1 3-8% 8-15% 15-25%	- 35 63 85 73 51 42 53 87 61	- -3-71 -20 (negative) 69 -83 -6 55 40 39 -31(negative)	Few studies.

BMP	Reference study	Study location	Buffer vegetation	Buffer width (m)	Phosphorus removal (%)	Orthophosphorus removal (%)	Study method
Riparian buffer Grassed	Dillaha (Dillaha, Reneau et al. 1989)	Virginia USA	Grass	4.5 9	49-85 65-93	69-83 48-81	Simulated rainfall
Riparian buffer Grassed	Magette (Magette, Brinsfield et al. 1989)	Maryland USA	Grass	15 30	41 53		Rainfall simulation, less effective after seasoning (initial removal greatest).
Riparian buffer Grassed	Syversen (Syversen 1995)	Norway	Grass	16 33 49	45-56 56-85 73	2-77 0-88 10	Slope 12-17%, with natural rainfall conditions.
Riparian buffer Grassed	Uusi-Kamppa (Usi-Kamppa and Ylantra 1996)	South Finland, Finland	Grass	33	20-36	0-62	Natural rainfall conditions.
Riparian buffer Grassed	Schwer (Schwer and Clausen 1898)	Vermont, USA	Grass	85	89	92	Removal highest in growing season.
Riparian buffer Grassed	Vought (Vought, Dahl et al. 1994)	Sweden	Grass	26 52	-	66 95	Greatest removal in first meter.
Riparian buffer Grassed	Stout (Stout, Pachepsky et al. 2005)	Hagerstown, USA	Grass	0.7 2% slope 4% slope 1.7 2% slope 4% slope 2.7 2% slope 4% slope	 59.4 65.8 60.1 57.6 60.2 60.9	-	Rainfall simulation.

BMP	Reference study	Study location	Buffer vegetation	Buffer width (m)	Phosphorus removal (%)	Orthophosphorus removal (%)	Study method
Fencing (grassed buffer indicative)	Merriman (Merriman, Gitau et al. 2006)	Arkansas, USA	Grass	-	76	-	8-15% slope. Based on 1 study.
Alternate water and shade	Merriman (Merriman, Gitau et al. 2006)	Arkansas, USA	Grass	-	-10 (negative)	-	8-15% slope. Based on 3 studies.
Contour swale (indicative)	Charles (Charles, Davies et al. 2008)	NSW, Australia	Grass, but results are for sub-surface removal and application	1(clay loam) 5(clay loam) 10(clay loam) 1(loam) 5(loam)	~99 ~99.5 ~99.9 ~98 ~99.1	-	Natural and simulated rainfall conditions for a field site. Study challenges were distributed from an absorption trench, which may be likened to the biomat experienced in a contour swale / soil interface.
Swale	NRC summary (National Research Council 2000)	-	-	-	29	34	9 studies.
Contour	Merriman (Merriman, Gitau et al. 2006)	Arkansas, USA	-	3 3-8% slope 4.5 03% slope 3-8% slope	- 30 26 26	-	Based on 3 studies.
Wet pond	NRC summary (National Research Council 2000)	-	-	-	48	52	36 studies.

BMP	Reference study	Study location	Buffer vegetation	Buffer width (m)	Phosphorus removal (%)	Orthophosphorus removal (%)	Study method
Constructed wetland	NRC summary (National Research Council 2000)	-	-	-	51	39	35 studies.