

Management of Blue-green Algal Blooms Within the Quiet Lakes, Patterson Lakes

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February 2001

Background

This discussion paper details Melbourne Water's approach to managing blue-green algal blooms within the Quiet Lakes since January 2000. It has been written to assist a request from the Patterson Lakes Advisory Committee that an independent expert critically reviews our approach.

History

The Quiet Lakes are situated in the suburb, Patterson Lakes, and consist of three connected waterbodies. The upper lake, Lake Legana, is connected to Lake Illawong, which is connected to Lake Carramar. Legana is the largest lake and Carramar the smallest. Maximum surface areas of Lakes Legana, Illawong and Carramar are approximately 6.5, 2.5 and 1 hectares, respectively. Maximum lake depth in the three lakes is around 2 to 3 metres, with Legana generally deepest.

The lakes were constructed in the 1970s, and in addition to providing water frontage for the adjoining properties, act as a retarding basin for stormwater from adjacent residential properties and roads. Run-off from adjacent yards is also channeled directly into the lakes. The catchment areas for Legana, Illawong and Carramar are about 27, 13 and 5 hectares, respectively.

All three lakes were established to provide primary contact recreation opportunity for the residents and are popular for swimming and boating in the warmer months. Some fishing also occurs.

Groundwater filling

Although the lakes receive stormwater, water levels are maintained by periodical filling from a groundwater pump that discharges into Lake Legana. The maximum discharge from the pump is around 2 ML/d, although the supply has been known to diminish considerably after consecutive drought years.

In order for the lakes to be filled from the groundwater supply, Lake Legana must fill first so that water can be gravity fed via an underground pipe into Lake Illawong. Lake Illawong and Lake Carramar, being at the same level, fill together and are joined by another underground pipe. A valve exists in the pipe between Lake Legana and Lake Illawong, allowing Legana to be isolated from the other two lakes. This valve remains closed for most of the year and is opened only when the lakes are being topped up with groundwater. There is no valve between Lake Illawong and Lake Carramar, only a coarse grille, so water may exchange freely between those lakes at any time.

A scour valve in Lake Carramar allows water to be drawn off the lakes system, via the council drainage system which outfalls into Patterson Lakes tidal waterways, near Ibis

Court. Lake Legana can also be drawn down via a valve and pipeline that feeds into the Gladesville Boulevard pump station. Water from Legana is then discharged into Patterson River.

Stormwater Overflows

Each of the Quiet Lakes contains an overflow pit, where excess water is discharged. Excess water from Lake Illawong is pumped via the McLeod Road pumping station into Wadsley Drain and water from Lake Carramar is discharged into an adjacent underground drain that flows into the Patterson Lakes tidal waterway system. Excess water from Lake Legana is discharged into Patterson River via the Gladesville Boulevard pumping station. Pumping stations exist adjacent to Lake Legana and Lake Illawong to assist in stormwater transfer. These pumps are not reversible.

The street drainage system is designed so that during storm events, the first flush is diverted away from the lakes.

A map of the Quiet Lakes system, including the groundwater pump and the stormwater system, is presented in Figure 1. Note that, although a 'Baywater Pipeline' is depicted in Figure 1, it has been decommissioned.

Aquatic Macrophytes

Although several types of macrophytes have existed at various stages in the life of the Quiet Lakes (Breen and Muir, 1989; Sainty *et al.* 1990), currently Charophytes are dominant in the three lakes. *Potamogeton pectinatus* (sago pondweed) and *Ruppia polycarpa* (widgeon grass) were also present prior to macrophyte planting in December 2000.

Prior to 1999, water plants were harvested from the Quiet Lakes on roughly an annual basis. This is in response to local demand, based on concerns of becoming tangled while bathing. Harvesting has been performed either by scooping detached fragments off the surface with a boat, or by a specialised harvester that cuts the weeds at a specified depth below water level.





Water Quality Problems

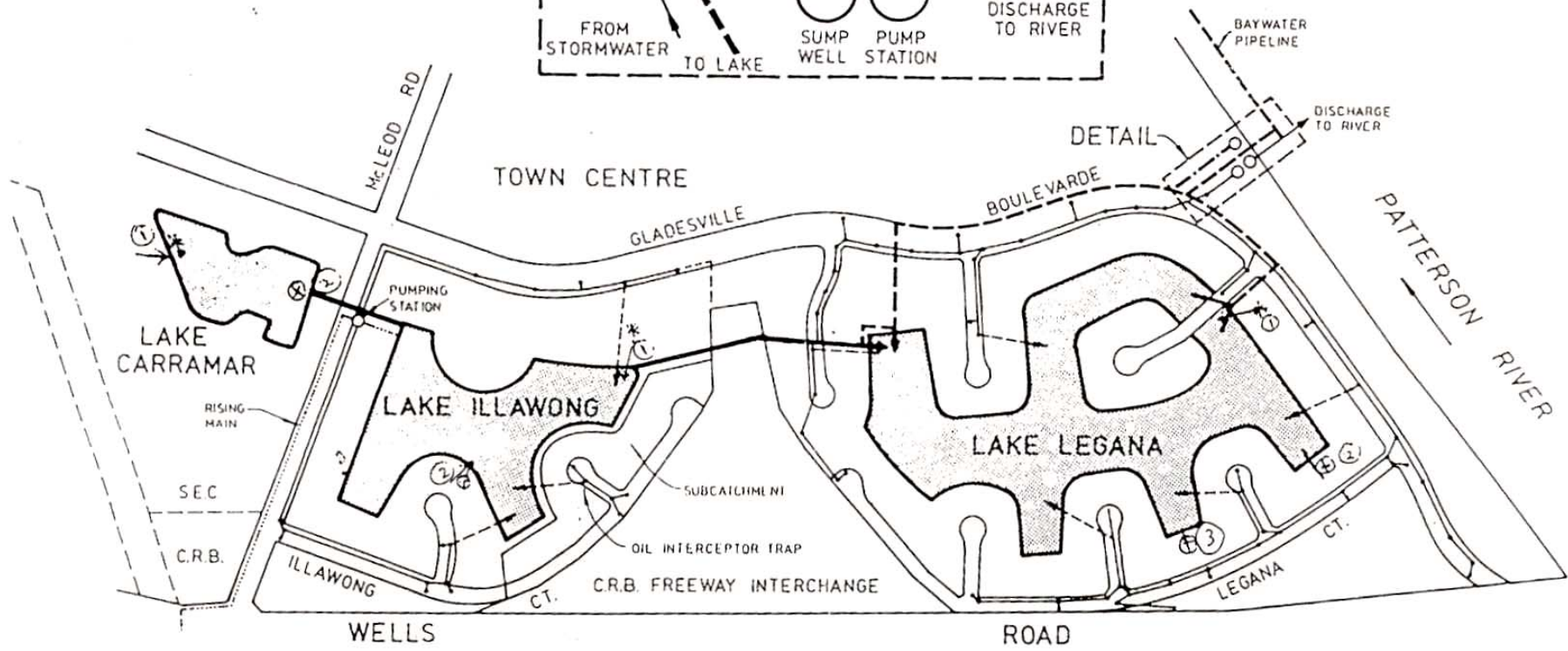
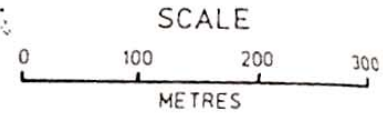
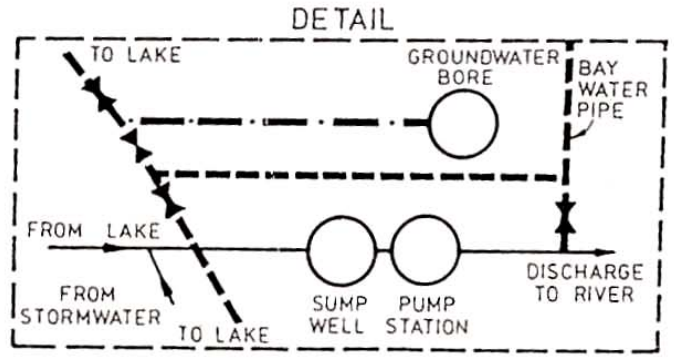
Surface water sampling has been conducted in these lakes since 1978, with the most regularly monitored indicators being: temperature, dissolved oxygen, conductivity, pH, water clarity, nutrients, biochemical oxygen demand and *E. coli*. The frequency of monitoring has varied considerably, with 2 to 3 monthly sampling throughout the year until 1993, then 1 to 2 monthly sampling during the summer only until 1997 and then weekly over the summer for *E. coli* and blue-green algae only. The latest change in monitoring was implemented to focus on the recreational risk – where monitoring is more frequent and indicators chosen to measure recreational suitability.

Summary statistics for historical water quality in the Quiet Lakes are presented in Table 1. The Quiet Lakes are slightly brackish (around 5,000 to 8,000 $\mu\text{S}/\text{cm}$) and alkaline (pH around 8.5 to 8.7). Surface water quality, in general, is quite good for an urban catchment – although organic nitrogen tends to be slightly elevated. On two occasions in recent years, *E. coli* levels in Lake Carramar and Lake Illawong were

Figure 1: Map of the Quiet Lakes System

LEGEND

-  SEAWATER FROM BAY WATER PIPELINE
-  BORE WATER
-  LAKE CONNECTING PIPES
-  OVERFLOW (SURFACE DEPRESSIONS)



**Table 1: Summary Water Quality Data
from the Quiet Lakes 1978 to 1999**

Lake Legana

	Temp	DO	%sat DO	Cond	PH	Turb	SS	NO3-N	NO2-N	NH3-N	TKN	T-N	O-P	T-P	E.coli	BOD5
min	9.5	1.9	75	782	6.9	1	1	0.003	0.001	0.010	0.73	0.74	<0.01	0.03	0	0.4
10%	12.0	6.8	78	5910	7.9	2	2	0.010	0.002	0.020	0.92	0.94	0.01	0.04	8	0.9
50%	18.0	9.3	88	7415	8.5	6	5	0.030	0.005	0.100	1.30	1.37	0.02	0.05	40	1.5
90%	22.3	8.9	98	8806	8.9	14	19	0.100	0.020	0.140	1.82	1.82	0.05	0.08	211	2.9
max	25.0	12.5	101	10300	9.4	21	61	0.290	0.080	0.650	1.90	1.94	0.35	0.45	600	6
n	105	80	14	110	107	98	94	91	67	92	13	13	93	14	129	106

Lake Illawong

	Temp	DO	%sat DO	Cond	PH	Turb	SS	NO3-N	NO2-N	NH3-N	TKN	T-N	O-P	T-P	E.coli	BOD5
min	9.0	2.0	82	3700	7.8	1	1	0.002	0.001	0.010	1.10	1.11	<0.003	0.02	4	0.2
10%	11.5	6.4	83	4700	8.2	2	2	0.010	0.002	0.015	1.20	1.22	<0.003	0.02	10	1
50%	18.0	9.2	87	6200	8.6	3	3	0.020	0.005	0.093	1.50	1.52	0.02	0.06	120	2.2
90%	22.0	11.0	90	8042	9.1	15	23	0.100	0.020	0.140	1.88	1.89	0.04	0.08	542	4.3
max	25.0	12.6	91	9470	9.6	24	72	0.100	0.140	0.760	2.10	2.14	0.16	0.10	3500	6.9
n	102	78	14	107	105	96	92	90	64	90	13	13	89	14	129	103

Lake Carramar

	Temp	DO	%sat DO	Cond	PH	Turb	SS	NO3-N	NO2-N	NH3-N	TKN	T-N	O-P	T-P	E.coli	BOD5
min	9.5	1.9	87	1800	7.9	1	1	0.002	0.001	0.007	1.30	1.30	<0.003	0.02	0	0.1
10%	11.5	6.8	88	3979	8.1	2	2	0.010	0.002	0.015	1.30	1.30	<0.003	0.03	15	0.7
50%	18.4	9.3	93	5773	8.7	4	2	0.020	0.005	0.050	1.50	1.50	0.02	0.05	120	1.6
90%	22.0	11.2	98	8432	9.1	11	18	0.100	0.020	0.116	2.18	2.20	0.04	0.10	712	3.3
max	24.1	13.6	99	10300	9.6	20	63	0.110	0.160	0.400	2.20	2.24	0.10	0.10	7900	5.6
n	102	79	14	106	106	95	91	88	63	89	13	13	88	12	128	103

slightly above that considered suitable for swimming (i.e. a geometric mean greater than 200 organisms/100 mL from at least five samples collected over a period of 42 days).

Although phytoplankton blooms are known to have occurred several times in the past (Breen & Muir 1989; Sainty *et al.* 1990), the species blooming were not identified. It is unknown, therefore, whether they were blue-green algal blooms. If there were instances of sickness from blue-green algal blooms, perhaps they were not attributed to water quality within the lakes (due to a general lack of public awareness of blue-green algal blooms prior to the 1990s).

On 26 February 1999, a blue-green algal bloom was identified in Lake Carramar during the Melbourne Water Summer Blue-green Algae Monitoring Program. The bloom consisted of the potentially toxic alga called *Oscillatoria* and was initially recorded at levels around 100,000 cells/mL. The recreation alert level is 20,000 cells/mL (DNRE 2001). As this type of algae grows on the bottom of waterways, algal mats were probably dislodged — resulting in surface scums in some parts of the lake. In response, warning signs were erected and all residents with access to the lake were provided with a letter explaining the situation. Department of Natural Resources and Environment (DNRE), Department of Human Services (DHS), Environment Protection Authority (EPA) and the City of Kingston were also notified. The bloom rapidly subsided and, following a safety period, warning signs were removed in late March 1999.

A minor bloom of blue-green algae was also present within Lake Illawong in February 1999 – indicating the susceptibility of that lake to blue-green algal blooms as well. In the following year, blue-green algal blooms were present again in both Lake Illawong and Lake Carramar, and also Lake Legana.

In all three lakes the bloom consisted of a blue-green alga called *Planktolyngbya*. Although *Planktolyngbya* is not known to produce toxins, being a blue-green alga, it has the potential to cause symptoms such as skin and eye rashes and vomiting (if swallowed) due to the presence of contact irritants within the cell wall structure (Jones 1994; NHMRC 1994; WHO 1999). In Lake Illawong the bloom initially consisted of a blue-green alga called *Anabaena cf. bergii* (at levels greater than 100,000 cells/mL), but within a fortnight, was replaced by *Planktolyngbya*.

These blooms persisted for several months, commencing in January/February 2000, peaking in March through to May, and then declining dramatically in late May 2000. Onset of the blooms was staggered, with Carramar blooming in mid-January, Illawong in early February and Legana in late February. Levels in Lake Legana were much lower than the other two lakes — peaking at 64,780 filaments/mL, while Illawong and Carramar peaked at 269,000 and 238,500 filaments/mL, respectively (Figure 2).

In immediate response to the blooms, warning signs were erected around all three lakes and letters distributed to the residents. These lakes were monitored on a weekly basis (three sites in each lake). NRE, DHS, EPA and the City of Kingston were also informed of the blooms.

The persistence of blue-green algal blooms in the Quiet Lakes highlighted the need to collect data that would improve our understanding of the current status of the system. Data could also reveal the likely factors contributing to (and triggering) algal blooms and to assist with measures to prevent blue-green algal blooms in the future. In March 2000, a proposal for data collection was developed by Waterways & Environment (Melbourne Water) and reviewed internally by Dandenong Valley Operations and externally by the Patterson Lakes Advisory Committee.

In October 2000, a *Planktolyngbya* bloom returned within Lake Legana. Until around Christmas day, levels were between 30,000 to 55,000 filaments/mL, but increased dramatically to 164,835 filaments/mL on 28 December 2000. There was a further increase to 308,500 filaments/mL on 18 January 2001.

Although the blooms were more severe in Lakes Carramar and Illawong the previous summer, this summer *Planktolyngbya* levels have remained well below 20,000 filaments/mL (up to 11,675 filaments/mL in Illawong and up to 1,275 filaments/mL in Carramar). Data collection and management actions are discussed in the following sections, as are possible explanations for this apparent improvement in water quality.

The reoccurrence of potentially toxic *Anabaena* spp. at 5,475 cells/mL in Legana and 1,600 cells/mL in Illawong on 18 January 2000, should be noted. This indicates the vulnerability of the system to form more serious blue-green algal blooms.

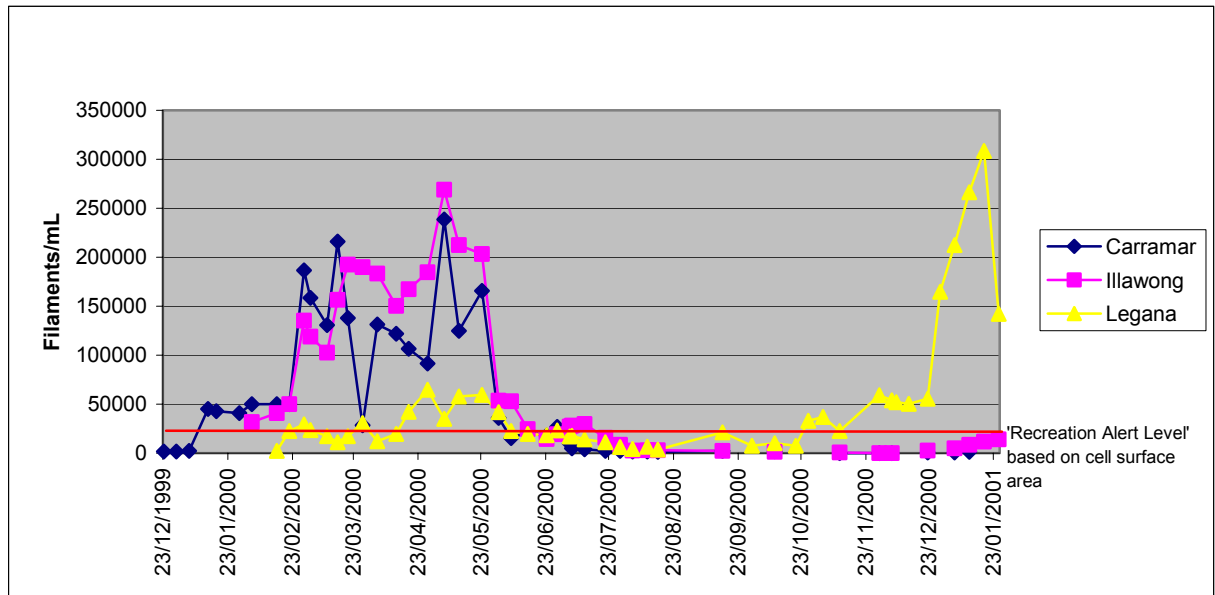


Figure 2: Quiet Lakes Average *Planktolyngbya* Levels 1999-2001

Management Actions Undertaken by Melbourne Water

In addition to standard public health warnings (signs and newsletters), Melbourne Water undertook a series of actions to manage the Quiet Lakes blue-green algal blooms. Management actions have been directed at both the short-term and importantly, the long-term sustainability of the lakes — where causes, rather than symptoms of algal blooms are addressed.

The Quiet Lakes have several attributes that are conducive to blue-green algal blooms, in particular they:

- have very little shading (increased light and temperature)
- have poor circulation (potential for stratification and long residence time)
- have a low abundance of aquatic macrophytes (little competition for nutrients and light, little habitat for zooplankton that may consume algae)
- are fed urban stormwater (typically of poor quality, with a high connectivity between houses and roads resulting in poor buffering against pollutants).

Until recently, a large population of carp inhabited the lakes. Carp could also be contributing to algal blooms e.g. re-suspension of sediments and subsequent replenishing of nutrients in the water column, and probably more significantly, causing a decline in aquatic macrophyte abundance either by consumption or physical disturbance. As macrophytes help to bind and stabilise sediments, water plant loss may also result in increased sediment re-suspension e.g. wind action.

The management actions undertaken by Melbourne Water to address the issue of blue-green algal blooms in the Quiet Lakes are discussed in detail below.

Water Quality Sampling

To build on the historical data set, additional surface water sampling (one location within each of the Quiet Lakes) commenced in February 2000 and will continue at least until March 2001. Samples are collected and analysed by AWT. The sampling frequency is fortnightly between November and March for field analyses (monthly for the rest of the year) and monthly all year round for the laboratory analyses. Relevant water quality indicators measured include:

Temperature	Oxidised nitrogen
Dissolved oxygen	Total Kjeldahl nitrogen
pH	Filterable reactive phosphorus
Conductivity	Total phosphorus
Turbidity	Total organic carbon
Suspended solids	Chlorophyll- <i>a</i>
Ammonia	

Results from the current water quality sampling regime are presented in **Figure 3**, but at this stage, it is difficult to discern meaningful patterns. Of interest, however, is the general decline in Chlorophyll-*a* and suspended solids in the late months of 2000 that followed netting of carp and evidence of aquatic plant re-growth.

Also of interest is the high phosphorus concentration observed in Lake Legana, on 15 September 2000, after which algal levels tended to rise. In the week prior to the 15

September, there was over 40 mm of rain. There are two other occasions within the algal data set where there are notable increases in *Planktolyngbya* i.e. 4-13 January 2000 and 22-28 December 2000 (Figure 2). Within a week prior to both of these increases



Figure 3: Water Quality Data from the Quiet Lakes 2000-2001

there were significant storm events (around 33 mm and 50 mm of rain respectively). It is possible that, because the Quiet Lakes appear to have low phosphorus levels, algal blooms could be triggered by phosphorus addition (e.g. from significant storm events) and subsequent 'luxury' uptake by phytoplankton. Further sampling, particularly during and immediately following storm events, would help test this hypothesis.

Phytoplankton Sampling

For the duration of the algal blooms in 2000, surface water sampling for algae was conducted weekly by AWT. From December 1999 through to April/May 2000, algal samples were collected from three evenly-spaced locations within each of the lakes – the purpose to better determine distribution of the blooms. *Planktolyngbya* results were found to be quite consistent throughout the lakes and subsequently, sampling continued from one site in each lake. *Planktolyngbya* scums have not been observed for the duration of the blooms.

In the absence of blooms, algal sampling was scheduled for fortnightly (November to March) and monthly (April to October), and was co-ordinated with water quality sampling.

Algal sample processing involved identification of all types of algae (including a broad estimate of abundance), with only blue-green algae being fully counted.

Planktolyngbya levels between 1999 and 2001 are presented in Figure 2. In these data, elevated algal levels have occurred during the warmer months (October to May). This indicates weather conditions, such as warmer temperatures and longer daylight hours, are important contributors to bloom formation.

Zooplankton Sampling

A qualitative snapshot of the zooplankton communities within the Quiet Lakes was conducted in late May 2000 — closely following the rapid decline of the algal blooms. Sampling was performed by towing a 50 µm-mesh plankton net behind a boat around each lake.

The Murray-Darling Freshwater Research Centre (MDFRC), who also provided advice on sampling methods, identified zooplankton samples. Of particular interest to Melbourne Water was the relative proportion of zooplankton grazers of blue-green algae.

Results of the initial zooplankton samples are presented in **Table 2**. The following four paragraphs are a summary of comments provided to Melbourne Water from MDFRC.

The *Daphnia* recorded in samples from Lakes Carramar and Illawong were potential grazers of blue-green algae. Although absent in the subsample, *Daphnia* were noted in a preliminary scan of the Lake Legana sample – therefore were likely to be in low numbers within the lake.

Daphnidae and Sulcanidae were common in the Lake Carramar sample. Daphnids ranged in size up to approximately 2 mm. Daphnids consume phytoplankton,

including blue-green algae. Ostracods and Harpacticoid copepods were also relatively common.

Daphnia spp. dominated the zooplankton community within the sample from Lake Illawong. Brachionidae rotifers, and Sulcanidae and Harpacticoid copepods were also present. The Lake Legana sample was dominated by Brachionidae rotifers (*Brachionus* spp.). Sulcanidae and Harpacticoid adults and Calanoid nauplii were also present.

Brachionidae rotifers are herbivores but their diet does not usually include blue-green algae. The specimens present were generally less than 0.5 mm in length. Sulcanidae and Harpacticoid copepods are typically predators (adults 2-3 mm in length).

Ostracods are generally detritivores. The taxa present were about 1 mm in size.

Table 2: Zooplankton identified within qualitative samples collected from Lakes Carramar, Illawong and Legana (8/6/2000)*

	Lake Carramar		Lake Illawong		Lake Legana	
	Count	Proportion%	Count	Proportion%	Count	Proportion%
Volume (mL)	50		50		50	
Aliquot Volume (mL)	5		2.5		1	
No. Aliquots	5		2		1	
Family Daphnidae (<i>Daphnia</i> spp.)	70	31	291	72	0	0
Family Sulcanidae (<i>S. conflictus</i>)	58	26	30	7	68	16
Ostracoda	43	19	0	0	0	0
Harpacticoida	51	23	63	16	54	13
Cleaned nauplii	4	2	2	0	19	5
Chydoridae	0	0	1	0	0	0
Brachionidae (<i>Brachionus</i> sp.)	0	0	19	5	272	66
Total	226	100	406	100	413	100

* Samples rinsed and re-suspended in 50 mL water. Successive aliquots were removed until a minimum of 200 animals was counted.

Groundwater Sampling

Groundwater from the Gladesville Boulevard pump to Lake Legana was sampled on 6 June 2000, and again on 6 February 2001. The purpose of this sampling was to help determine the quality of water being used to top up the lakes. Results from 6 June 2000 are presented in Table 3. The results from sample collected on 6 February 2001 are currently unavailable. Electrical conductivity, and levels of total nitrogen and total phosphorus in the first groundwater sample are similar to surface water levels in the Quiet Lakes (although ammonia is a proportionally greater component of total nitrogen in the groundwater sample).

Table 3: Groundwater results from the Gladesville Boulevard pump to Lake Legana (sampled 6 June 2000)

Electrical Conductivity	7400 μ S/cm
Nitrate + Nitrite as N	0.005 mg/L
Ammonia as N	0.55 mg/L
Total Kjeldahl Nitrogen as N	0.64 mg/L
Filterable Reactive Phosphorus as P	<0.003 mg/L
Total Phosphorus as P	0.034 mg/L

Lake Water Quality Profiling

A depth profile of water quality in each lake was undertaken to determine presence of thermal stratification. Thermal stratification has the potential to trigger blue-green algal blooms, particularly due to nutrient release from sediments under low oxygen conditions.

Water quality profiling has been conducted on two occasions during algal blooms i.e. 2 February 2000 (all three lakes) and 11 January 2001 (Lake Legana). Water quality indicators measured on 2 February 2000 were water temperature, dissolved oxygen, electrical conductivity and nutrients. Nutrients were sampled where evidence of stratification was found. Results are presented in Tables 4 and 5, and indicate that all three lakes are relatively well mixed, with weak stratification in a few isolated areas.

On 11 January, water quality profiling was conducted in Lake Legana. These results indicate that, similar to 2 February 2000, the lake is relatively well mixed or perhaps weakly stratified (Table 6). Had there been distinct stratification within Lake Legana at the time, water quality profiling also would have been conducted in Lakes Carramar and Illawong – to determine whether a difference in extent of stratification could help explain the absence of blooms in Carramar and Illawong as opposed to Legana.

Table 4: Water Quality Profiling of the Quiet Lakes 2 February 2000 (sites evenly spaced around the lakes)

CARRAMAR	BOTTOM (10 cm above bed)			TOP (10cm below surface)			DEPTH (m)
	DO mg/L	TEMP °C	EC µS/cm	DO mg/L	TEMP °C	EC µS/cm	
Site 1	6.8	23.8	7850	6.5	23.7	7820	2.0
Site 2	6.4	23.8	7830	6.4	23.8	7830	1.9
Site 3	4.2	23.6	7700	6.6	23.8	7850	1.9
Site 4	6.7	23.7	7850	6.3	23.7	7870	1.6
Site 5	7.0	23.7	7850	6.6	23.7	7850	1.7
Site 6	6.9	23.7	7840	6.6	23.7	7850	1.8
Site 7	6.9	23.7	7840	6.7	23.6	7840	1.8
Median	6.8	23.7	7840	6.6	23.7	7850	1.8
Average	6.4	23.7	7823	6.5	23.7	7844	1.8

ILLAWONG	BOTTOM (10 cm above bed)			TOP (10cm below surface)			DEPTH (m)
	DO mg/L	TEMP °C	EC µS/cm	DO mg/L	TEMP °C	EC µS/cm	
Site 1	7.0	23.4	9200	7.3	23.5	8980	1.8
Site 2	7.0	23.4	8960	7.1	23.6	8960	2.0
Site 3	6.6	23.5	8990	7.1	23.6	8980	2.1
Site 4	3.0	23.2	8970	7.1	23.7	8970	2.1
Site 5	6.1	23.4	8970	7.0	23.7	8950	2.0
Site 6	6.4	23.4	8970	7.2	23.7	8970	2.0
Site 7	5.7	23.4	9200	7.2	23.7	8970	2.0
Site 8	6.4	23.5	9200	7.2	23.7	8980	1.8
Site 9	7.3	23.6	8980	7.3	23.7	8970	0.2
Median	6.4	23.4	8980	7.2	23.7	8970	2.0

Average	6.2	23.4	9049	7.2	23.7	8970	1.8
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Table 4: continued....

LEGANA	BOTTOM (10 cm above bed)			TOP (10cm below surface)			DEPTH (m)
	DO mg/L	TEMP °C	EC µS/cm	DO mg/L	TEMP °C	EC µS/cm	
Site 1	0.3	22.1	9300	7.6	23.9	9200	2.7
Site 2	6.1	23.7	9090	7.7	24.0	9060	1.9
Site 3	6.8	23.7	9090	7.7	24.0	9060	1.9
Site 4	6.8	23.6	9300	8.0	23.9	9200	2.3
Site 5	6.1	23.6	9300	8.1	24.0	9200	2.1
Site 6	7.0	23.6	9300	8.1	23.9	9200	2.1
Site 7	7.0	23.6	9200	8.0	23.8	9200	2.4
Site 8	7.3	23.6	9040	8.0	23.9	9050	2.1
Median	6.8	23.6	9250	8.0	23.9	9200	2.1
Average	5.9	23.4	9203	7.9	23.9	9146	2.2
Site 1	Anoxic layer 0-40 cm from bottom						

Table 5: Water Quality Samples Collected from Surface and Bottom Waters within the Quiet Lakes at Lake Carramar Site 3, Lake Illawong Site 4 and Lake Legana Site 1, 2 February 2000

	Carramar	Carramar	Illawong	Illawong	Legana	Legana
	BOTTOM	TOP	BOTTOM	TOP	BOTTOM	TOP
Ammonia as N	0.1	0.03	0.03	0.03	0.08	0.05
Nitrate + Nitrite as N	0.03	0.02	<0.01	0.01	0.01	0.02
Total Kjeldahl Nitrogen as N	2.6	1.4	1.4	1.1	1.5	1.3
Total Phosphorus as P	0.4	0.16	0.2	0.28	0.21	0.17

Table 6: Water Quality Profiling of Lake Legana, 11 January 2001. Sites evenly spaced around the lake.

	BOTTOM (10 cm above bed)			TOP (10cm below surface)			DEPTH (m)
	DO mg/L	TEMP °C		DO mg/L	TEMP °C		
Site 1	6.2	26.0		6.6	24.0		2.4
Site 2	5.2	23.5		6.7	25.5		2.8
Site 3	5.9	23.5		6.6	26.0		2.5
Site 4	6.8	23.5		6.8	26.0		2.6
Site 5	5.0	23.0		6.8	26.0		2.9
Median	5.9	23.5		6.7	26.0		2.6
Average	5.8	23.9		6.7	25.5		2.6

Sediment Sampling

On 9 June 2000, sediment samples were collected from three locations within each lake. These samples were analysed by WSL for nutrients (total Kjeldahl nitrogen and total phosphorus) using the standard <63 µm particle size fraction. Total organic carbon was analysed using whole sediments. The purpose of this sampling was to indicate the store of nutrients potentially available for release to the water column. Sediment results are presented in Table 7.

Table 7: Nutrient Levels within Quiet Lakes Sediments *

Site	Total Phosphorus mg/kg	Total Kjeldahl Nitrogen mg/kg	% Sediment Particles <63 µm	Total Organic Carbon %
Carramar Site 1	500	6,200	44	3.2
Carramar Site 2	500	8,100	<1	
Carramar Site 3	61	9,000	5	
Illawong Site 1	340	5,300	51	3.3
Illawong Site 2	270	4,800	<1	
Illawong Site 3	390	6,700	20	
Legana Site 1	140	4,400	23	2.5
Legana Site 2	160	4,500	61	
Legana Site 3	150	2,000	62	

*<63 µm particle size fraction for phosphorus and nitrogen analyses, and whole sediment analysed for total organic carbon.

In a recent Melbourne Water study of sediment quality within 15 wetlands around Melbourne (a total of 45 samples), total Kjeldahl nitrogen ranged from 148 to 5,110 mg/kg and total phosphorus ranged from 55 to 2,150 mg/kg. These results were also based on the <63 µm particle size fraction. Median Kjeldahl nitrogen and phosphorus levels for the 45 samples were 1,665 and 457 mg/kg, respectively. In the absence of standard guidelines and more data, results suggest that Quiet Lakes sediments have elevated nitrogen levels, while phosphorus is comparatively low. Within the same 15 wetlands, total organic carbon ranged from 0.4 to 6.5%, with a median and 90th percentile of 1.7 and 5.64%, respectively. Once again, in the absence of more data, this would suggest moderate levels of organic matter within Quiet Lakes sediments.

Monash University (Water Studies Centre) is conducting research regarding performance of various compounds to bind nutrients within sediments and restrict nutrient release for phytoplankton consumption. Upon request for potential study sites, Melbourne Water encouraged Monash University to collect sediment cores from the Quiet Lakes. Not only was this seen as an opportunity to better understand sediment dynamics within the lakes, but also consider the applicability of these compounds for managing algal blooms within the lakes. Preliminary results suggested that under anoxic conditions the sediments release substantial amounts of nitrogen, but little phosphorus.

In addition to the Monash University study, RMIT (as a final environmental engineering degree project) is undertaking an environmental risk assessment investigating the use of 'barrier' compounds to control blue-green algal blooms. The work will consider the potential environmental impacts from addition of such compounds. Melbourne Water assisted in providing information to enable use of the Quiet Lakes as a case study. An outcome is not expected until late 2001.

Gathering Additional Information

As well as the collection of current environmental data, information regarding the history of the lakes was sought from reports (e.g. Breen and Muir 1989; Breen and Connor unpublished; Sainty *et al.* 1990) and discussions held with past managers of

the lakes. Informal discussions were also held with residents during most sampling visits.

Melbourne Water's aerial photographs of the three lakes taken on 15 December 1986, 19 March 1988 and 9 March 1996 were viewed. In all three photos Lake Legana is considerably greener than the other two lakes. Although the discolouration may be due to water plants, the consistency of the colour throughout Lake Legana (especially 9 March 1996) appears more typical of phytoplankton blooms.

Management Actions Undertaken by Melbourne Water

Operation of Bore Pump

An early management response was to continuously operate the groundwater pump, the purpose being to dilute algae and decrease residence time of water within the lakes. It was acknowledged that this action (due to the low maximum pumping rate) was unlikely to result in significant water quality improvement.

Maintenance of Drainage System

In April 2000, the connecting drain pits were cleaned and in May 2000, the valve allowing the lowering of the lakes from Carramar was repaired.

Macrophyte Planting

Aquatic macrophytes are believed to play an important role in controlling algal blooms within the Quiet Lakes. History demonstrates a link between water plants, carp and blooms, as evidenced by the following extracts..

1) Extracts from Breen & Muir (1989):

“it should be stressed that the growth of aquatic plants, including weeds, is beneficial to the overall quality and stability of the resource (Quiet Lakes). In particular, the effect of aquatic plant growth.....is to reduce, among other things, turbidity, nutrients, bacteria and algae in the water column.”

“1983: Condina (19 Jul) weed cutting noted to result in increased algal growth (phytoplankton).”

“1983: Nuttall (2 Nov) weed cutting increased turbidity and frequently resulted in an algal bloom.”

“1985-88: Reports from this period noted a cycle of weed cutting, turbidity increase, algal blooms, followed by turbidity decreases and subsequent water plant growth.”

“1989: Condina prepared comments for Patterson Lakes Advisory Committee meeting (8 Feb). It was stressed that plant growth of some type was not only inevitable, but desirable in water bodies such as the Quiet Lakes.”

“1989: Stomach content analysis of Carp caught in Legana revealed mainly aquatic plants.”

2) Extracts from Sainty *et al.* (1990):

1989/1990

“Lake Legana had poor plant growth and a phytoplankton bloom. Numbers of fish appeared to be high.”

“Lake Illawong had dense beds of water plants until spring 1989. Following that time, the plants disappeared and it seems that the water became highly discoloured by phytoplankton. Carp numbers appeared to have reached a critical level and had completely eaten and/or uprooted the water plants.”

“Lake Carramar was considered to be in the best condition of the three lakes. Water plant growth was high and numbers of carp appeared to be lower.”

In reference to the management strategy: *“(the) plan must strike a compromise between the users requirements for clean, clear water and a balanced, stable ecology. It is not possible to achieve acceptable water quality in the absence of plants”*

“Recent experience in Lake Illawong strongly indicates that the management of aquatic plant biomass and the number of fish in the lakes should be closely coordinated.

“(If not,) the numbers of fish may develop to the point where the plant biomass cannot support them (the fish), particularly after a plant harvest.”

“This appears to have occurred in Lake Illawong and the result was near eradication of macrophytes from the lake and some fish kills”.

Prior to onset of the blue-green algal blooms in January 2000, several visual inspections of all lakes indicated that water plants were extremely sparse. This may have been the outcome of plant harvesting performed around two years earlier, after which the balance of carp to plant biomass had shifted greatly and resulted in carp stripping the lakes of vegetation. Sainty *et al.* (1990) gave a similar explanation for extensive water plant loss in Lake Illawong during 1989/90. Water plants are critical for algal control because they compete for nutrients (including epiphyte nutrient processing) and light, help oxygenate the water column and provide habitat for zooplankton that may feed on algae (e.g. *Daphnia* spp.).

Although there was significant re-growth of water plants by October 2000, to assist in water plant recovery and the establishment of a more diverse and robust plant community, Melbourne Water conducted some planting in December 2000. A diverse plant community is desirable so that the system is more likely to withstand changes in environmental condition (in particular, water quality, water levels and dominant species e.g. carp).

A total of 600 plants were planted by Wetland Ecosystems around the perimeter of the lakes – accounting for a length of 300 m. Five sections of plantings were placed in Lake Legana. With macrophytes already quite well represented in Lakes Carramar

and Illawong, only two sections of plantings were placed in those lakes. To help protect the establishing plants from birds and fish, guarding was placed around plants. During establishment, monthly inspections of plantings by the aquatic plant contractor will occur. A recent inspection of plantings indicate that they are responding well, particularly in Lake Legana (this may have something to do with the prior drop in water level and subsequent triggering of flowering and seeding not seen in the Carramar and Illawong plants).

Species planted were *Potamogeton pectinatus* (sago pondweed), *Ruppia maritima* (sea tassel), *Ruppia polycarpa* (widgeon grass), *Myriophyllum salsugineum* (watermilfoil) and *Mimulus repens* (creeping monkey-flower).

Carp Control

Removal of carp was considered particularly important because of grazing pressure they exert on water plants within the lakes. A relationship has been demonstrated between a lack of plants and algal blooms in the Quiet Lakes (see 'Macrophyte Planting' section). As well as by consuming aquatic plants, it is a common belief that carp may contribute to algal blooms by their bottom-feeding behaviour – where sediments are re-suspended and subsequently, there is potential for nutrient replenishment to the water column.

Initially electrofishing was conducted in Carramar and Illawong early in 2000. Electrofishing was the technique of choice based on a very successful account of carp removal in November 1985, where about 1000 carp were captured from Legana, along with two bream and fifteen short-finned eels. The total weight of carp was 950 kilograms (Breen and Muir 1989).

The recent electrofishing effort was unsuccessful, which according to AWT (the laboratory conducting the work), was due to elevated electrical conductivity (i.e. >3000 $\mu\text{S}/\text{cm}$). With comparable conductivity in 1985 and 2000, further investigation revealed that, although electrofishing equipment was used, the bulk of the success in 1985 was attributed to the use of seine nets. Electrofishing equipment was said to only help by herding fish.

Following the electrofishing setback, subsequent carp removal was conducted using seine nets only. Streamline Research Pty Ltd, was commissioned to co-ordinate netting.

Fish were netted in Lakes Carramar and Illawong on 19 June and 7 August 2000. Additionally, 10 bait traps (with light sticks) were set overnight in each of the two lakes on 18-19 July 2000. Lake Legana netting occurred on 23 and 25 August 2000, and 25 bait traps (with light sticks) were set overnight on 24-25 August 2000. Additional netting of Lake Legana occurred on 5, 6 and 12 December 2000. Prior to netting, water levels were dropped slightly to improve the catch. A preliminary netting effort within Carramar was undertaken in conjunction with residents in March 2000.

Table 8 shows the results of the netting program in Lake Carramar. A total number of 62 fish were captured of which 28 were goldfish and 33 carp. Flat-headed gudgeon, the only native species, was caught using bait traps. Gut contents revealed a black

sludge in the stomach of carp and a green sludge in the goldfish. Most of the fish examined were female and full of eggs. Several mirror carp were also caught.

Table 8. Fish captured in Lake Carramar (June to August 2000)

Date	Technique	Species	Common name	No.	Length (mm)	Weight (g)
19/06/00	Seine netting	<i>Carassius auratus</i>	Goldfish	4	250-290	460-660
		<i>Cyprinus carpio</i>	Carp	21	340-660	1000-4120
19/07/00	10 bait traps	<i>Philypnodon grandiceps</i>	Flat-headed gudgeon	2	53-65	1.1-3.1
07/08/00	Seine netting	<i>Carassius auratus</i>	Goldfish	24	220-300	320-780
		<i>Cyprinus carpio</i>	Carp	12	370-590	1180-4780

Table 9 shows results of the netting program in Lake Illawong. A total number of 286 fish were captured, including three goldfish, 281 carp and 2 flat-headed gudgeon. The flat-headed gudgeon were caught using bait traps.

Table 9. Fish captured in Lake Illawong (June to August 2000).

Date	Technique	Species	Common name	No.	Length (mm)	Weight (g)
19/06/00	Seine netting	<i>Cyprinus carpio</i>	Carp	149	280-520	410-2600
19/07/00	10 bait traps	<i>Philypnodon grandiceps</i>	Flat-headed gudgeon	2	55-75	1.6-3.9
07/08/00	Seine netting	<i>Carassius auratus</i>	Goldfish	3	no data	no data
		<i>Cyprinus carpio</i>	Carp	132	no data	no data

Large carp and goldfish (no juveniles) dominated Lake Carramar. Lake Illawong had a larger number of fish and was also dominated by carp. Fish present in Illawong had a broader size class than those in Carramar.

Table 10 shows results of the netting program in Lake Legana on 23 and 25 August 2000. A total number of 192 fish were captured, of which 6 were goldfish and 167 carp. In addition, 15 black bream were caught in the seine nets and four flat-headed gudgeon caught using bait traps.

A total of 89 carp were transported to the Snobs Creek fish hatchery for inclusion in the Carp Program. Lengths, weights and age classes for these fish will be examined. Of the carp captured, a large proportion were between 4-6 kg (no juvenile carp, including none retrieved in a smaller mesh seine). Several mirror carp and black bream (up to 1 kg in size) were included in the catch.

Table 10. Fish captured in Lake Legana (23-25 August 2000). * only 2 examined

Date	Technique	Species	Common name	No.	Length (mm)	Weight (g)
'23/08/00	Seine Netting	<i>Carassius auratus</i>	Goldfish	1		
		<i>Cyprinus carpio</i>	Carp	126		
		<i>Acanthopagrus butcheri</i>	Black Bream	8		
'24-25/08/00	25 bait traps	<i>Philypnodon grandiceps</i>	Flat-headed gudgeon	4	82-97	<10
'25/08/00	Seine Netting	<i>Carassius auratus</i>	Goldfish	5		
		<i>Cyprinus carpio</i>	Carp	41		
		<i>Acanthopagrus butcheri</i>	Black Bream	7*	320-325	900

Additional netting of fish in Lake Legana on 5, 6 and 12 December 2000 was carried out to remove as many individuals as possible over a 3-day period, but also to determine the potential number of fish within the lake (carp and goldfish).

Using a 54-mm seine net, the first haul captured 7 carp, 6 goldfish and 3 bream. The bream were released unharmed, however, 6 carp and 6 goldfish were tagged and released in various locations throughout the lake. The purpose of releasing tagged fish was to gain some idea of the populations of carp and goldfish that exist. It should be noted that fish of 25 cm in length could pass through the 104 mm-seine net and some of the goldfish used in the tagging experiment were in this size range.

A total of 122 carp and 17 goldfish were removed from Lake Legana during the three days. Ten flat-headed gudgeon (found in a fish trap that was dragged from the lake) and 13 black bream were also captured and then released. It is possible that the bream were recaptured on several occasions.

Five of the 6 tagged carp and 1 tagged goldfish were recovered. Based on tag recovery, it was estimated that the current carp population (fish greater than 25 cm in size) could be as low as 24.

The goldfish population was more difficult to estimate as only 1 of 6 tagged fish was recovered. It is possible that some of the tagged fish, which were only about 25 cm in length, continually avoided capture by slipping through the net. The goldfish population may be as large as 102. It is more likely, however, that as only 23 were removed from August and December netting programs, the population may be smaller (with many of the fish caught greater than 25 cm in length).

Data on weights, length and gonad development on 89 carp collected from Lake Legana in August 2000 were supplied by Snobs Creek fish hatchery in December 2000 (age data are not available yet). These data show that most of the fish captured in August were close to spawning. Both carp and goldfish are expected to have bred in Lake Legana, supported by observations of juveniles of the year in the shallows on 12 December 2000. It was recommended that future netting programs to remove carp should, therefore, be conducted no later than early August to ensure that yearly spawning is minimised.

Recent netting to control carp appears to have been successful, with significant plant re-growth observed in all three lakes on 19 October 2000. Re-growth, probably a response to a decreased grazing pressure from carp, was particularly extensive in Lakes Carramar and Illawong. Less re-growth in Lake Legana may be due to netting occurring a few weeks later than the other lakes and a smaller percentage of carp removed (deeper and wider lake profile where carp are better able to evade nets).

Charophytes, observed on 19 October 2000, dominated the relatively thick beds of water plants in Carramar and Illawong. Although much less abundant, Charophytes were also dominant in Legana. *Potamogeton pectinatus* and *Ruppia polycarpa* were also observed (most abundant in Legana), as were small growths of benthic macroalgae in addition to Charophytes (i.e. *Enteromorpha* and a filamentous green).

One notable feature of netting Lake Legana in December was the apparent increase in aquatic plant growth since netting in August. When a seine net was pulled in, the amount of mud retrieved in the net was considerably less than during August. Gut examination of 2 large carp found mostly Charophytes, whereas previous examination in August found only black sludge.

In December 2000, a more thorough inspection of Lake Carramar (snorkelling) revealed a greater abundance of macrophytes than expected – with an estimated 70% cover of the lake bed, to a length of up to around 0.5 m. Macrophytes were mostly Charophytes and were generally absent in deepest areas (where light is expected to be minimal). The upper 20 cm or more of lake sediment seemed to consist mostly of fine particles and appeared more stable where macrophytes were present.

Estuary Perch

Acknowledging that carp netting using seine nets may be difficult in the future when macrophytes are better established, alternatives for carp control have been considered.

Chemical treatment (i.e. the addition of rotenone) was rejected for several reasons, including the presence of native fish within the lakes, risk to other aquatic fauna and restrictions under the State environment protection policy. In addition, even with 100% mortality of carp and goldfish, there would be no guarantee that nuisance species would not be re-introduced into the system.

It was decided that to help suppress the carp population, a native fish should be introduced that could potentially predate on juvenile carp and goldfish. After a discussion with Freshwater Ecology division within DNRE, it was agreed that the most appropriate species to introduce is *Macquaria colonorum* (estuary perch). Estuary perch were chosen for a number of reasons including:

- they are piscivorous
- occur naturally within southern Victoria
- there is little to no stock structuring of populations, i.e. good genetic mixing (unlike Australian bass)
- Lake Legana is brackish, which suits this species.

On 6 December 2000, Melbourne Water submitted an application for a permit to stock Lake Legana with estuary perch. On 3 January 2001, the application was approved.

The aim of this experiment is to determine the effectiveness of introducing estuary perch in suppressing or controlling carp numbers within Lake Legana. The approach involves the following stages:

- four days of carp netting (seine nets)
- planting of additional aquatic macrophytes for fish habitat
- introduction of estuary perch once macrophytes are established (up to 50 individuals with a focus on 1 to 2 year-old fish)
- monitoring the fish community.

Proposed methods for measuring success of stocking were:

- annual netting (fyke nets, seine netting and bait traps) for at least 3 to 5 years

- regular visual inspections by Melbourne Water staff
- inspection to determine survival of estuary perch and also impact on carp recruitment.

In addition to netting carp and introduction of estuary perch, it also suggested that the residents themselves could be encouraged to fish-out carp – possibly an annual event or competition. If considered appropriate, coarse angling clubs could also be invited to attend. With encouragement of recreational fishing, catch and release of estuary perch should be emphasised as being for the good of the lake.

Daphnia Seeding

It is hoped that plant re-growth in Lakes Carramar and Illawong is extensive enough to prevent a severe algal bloom in the summer of 2000-2001. Former doubt regarding the resilience of Legana soon proved correct. The intensification of the bloom in Legana was also thought to be a threat to plant re-growth (phytoplankton soaking up light before it could reach the plants on the lake bed).

Because management options to control algal blooms (once they occur) in the Quiet Lakes are limited, Melbourne Water explored the possibility of introducing *Daphnia* (water fleas) to consume algae and help hold-off blooms. To reduce the risk of this exercise (e.g. *Daphnia* preferentially feeding on other algal groups and effectively encouraging *Planktolyngbya* growth) Melbourne Water first conducted a small laboratory experiment.

Details regarding methods used for the ‘*Daphnia* feeding on *Planktolyngbya* experiment’ are given in **Appendix 1**. Results of the experiment are summarised in **Figure 4**. Compositions of the zooplankton community used in the experiment are presented in **Table 11**.

Although all three tanks declined in *Planktolyngbya* levels over the two-week period (possibly light limited), algal densities seemed proportionally lower in the treatment tanks – particularly after one week. Interestingly, *Daphnia* numbers increased in the treatment tanks over the two weeks, while other zooplankton tended to decline. Acknowledging the limitations of the experiment, the results provided enough evidence that it was worth attempting to seed the lakes with *Daphnia*.

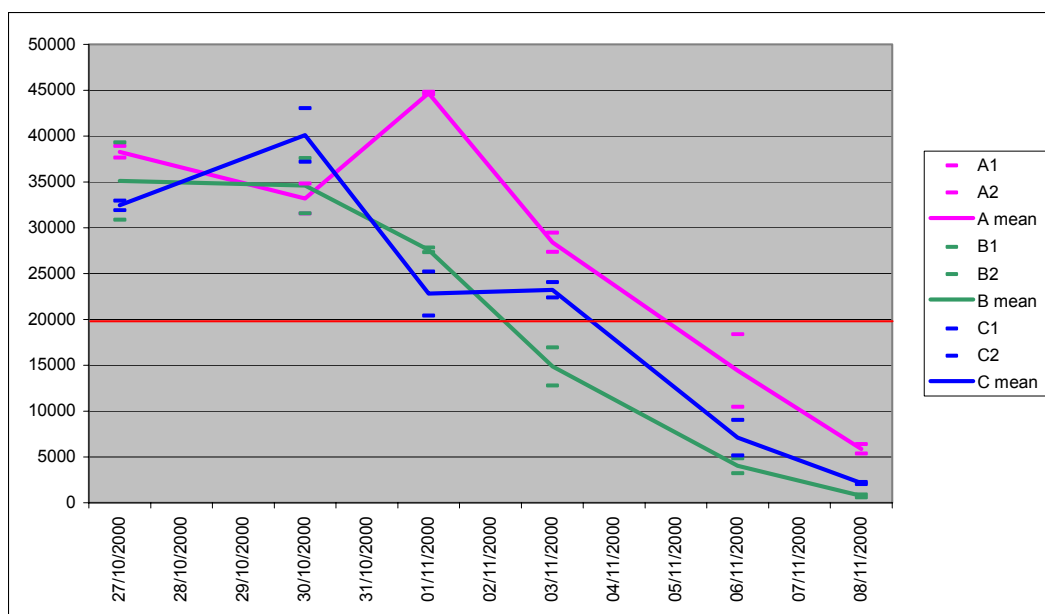


Figure 4: Planktolyngbya Levels with Varying *Daphnia* (& other Zooplankton) Densities. A=control, B=500mL zooplankton, C=250mL zooplankton

Table 11: Composition of zooplankton community added to the treatment tanks for the *Daphnia* feeding on *Planktolyngbya* experiment. B= Treatment 500 mL zooplankton, C= Treatment 250 mL zooplankton

Taxa	B Start org/L	B Start %	C Start org/L	C Start %	B End org/L	B End %	C End org/L	C End %
Cladocera								
<i>Alona</i> sp.	1	1	0.5	1	0	0	3	1
Ceriodaphnia	0.5	0	0.2	0	0	0	0	0
<i>Daphnia</i> cf. <i>carinata</i>	55	32	27	32	115	56	105	52
<i>Daphnia</i> sp.	0	0	0	0	10	5	8	4
Juvenile cladocerans	4	2	2	2	24	12	8	4
Moina	0.5	0	0.2	0	0	0	0	0
Copepoda								
<i>Boeckella</i> sp.	78	46	39	46	24	12	9	4
Calanoid copepodites	25	15	13	15	16	8	9	4
Cyclopoid copepods	2	1	1	1	0	0	3	1
Nauplii	4	2	2	2	0	0	1	0
Rotifera								
cf. <i>Ascomorpha</i>	0	0	0	0	15	7	55	27
Other Rotifers	2	1	1	1	1	0	0	0
Total	171	100	86	100	205	100	201	100

In December 2000, 40x20 L drums of concentrated *Daphnia* (and other zooplankton) were harvested from Edithvale Wetlands using 250 µm aquatic macroinvertebrate sweep nets.

Drums were filled to about $\frac{3}{4}$ capacity to allow for oxygen exchange and were transported to Lake Legana. The holding period was estimated to be less than 30 minutes. Harvested *Daphnia* were released into Lake Legana from both sides of the

Illuka Island bridge – where there seemed to be more refuge via water plants than other sections of the lake.

Following release of *Daphnia*, using a 28.6 L zooplankton trap with 80 µm mesh, sampling was conducted weekly at two sites in Lake Legana – the Illuka Island bridge and at the end of Illuka Court. After about 2 months, only one *Daphnid* was observed – indicating that the seeding trial, at least in the short-term, had been unsuccessful. It is suspected that the current lack of refuge for *Daphnia* rendered them vulnerable to predation from other zooplankton and fish. In particular, back swimmers (Notonectidae) were abundant in the lake and small carp were observed around the time of *Daphnia* release.

To confirm the possibility of back swimmer predation on *Daphnia*, Melbourne Water conducted a simple experiment, which involved the use of nine 375 mL jars – four control and five treatment. To all jars, water from Lake Legana and 10 *Daphnids* were added. To each of the treatment jars, three back swimmers were also added. Within 24 hours the results were clear. One hundred percent of the *Daphnids* had been consumed in treatment jars (only empty cases remaining), while <5% of *Daphnids* in control jars had died. Interestingly, *Daphnids* were difficult to retrieve from Edithvale Wetlands for the experiment – with the zooplankton community having dramatically shifted to a back swimmer dominated state in the ‘time-period’ since the first harvesting.

Due to a lack of initial success and poor *Daphnid* supply, the addition of further zooplankton has been postponed indefinitely. It is possible Lake Legana could appreciably respond to seeding of *Daphnids* when waterplants are better established and provide improved refuge.

Informing Residents

In addition to active management of the lakes, an important component of addressing the algal bloom issue was to keep residents informed. Consequently, several update notices were hand delivered by Melbourne Water staff. These notices included information about the status of algal blooms, public health risks, management actions implemented and management actions proposed. They also encouraged residents to contact the Dandenong office should they require additional information.

One notice gave special attention to how residents could contribute to maintaining a healthy lake system, e.g. wise use of fertilisers, regular removal of leaf litter and grass clippings, not washing cars or boats on the street or hard surfaces flowing directly into gutters, and cleaning up after pets.

Reasons for Rejecting Certain Management Actions

The following management options were considered but were eventually rejected. Information regarding aerators, dissolved air filtration and activated carbon was provided by Melbourne Water’s Water Group.

Draining of Lakes

It was thought that draining of the Quiet Lakes, and subsequent re-filling, may help to clear the bloom. Draining required discharge to the Patterson Lakes tidal system from Lake Carramar or, alternatively, from Lake Illawong into Wadsleys Drain and subsequently into Kananook Creek. Lake Legana can be drained into Patterson River via the Gladesville Boulevard pump station. The risk with draining was the bloom spreading into other high-profile recreational areas.

Because there was no information on saline tolerance of *Planktolyngbya*, Melbourne Water conducted a laboratory experiment. Methods are described in **Appendix 2**. Results are summarised in **Figure 5**. Original electrical conductivities were 10,000 $\mu\text{S}/\text{cm}$ in the control, 44,000 $\mu\text{S}/\text{cm}$ in the 1:4 treatment and 32,000 $\mu\text{S}/\text{cm}$ in the 1:2 treatment. Final electrical conductivities after 9 days were 9,820 $\mu\text{S}/\text{cm}$, 42,400-42,500 $\mu\text{S}/\text{cm}$, and 31,400 $\mu\text{S}/\text{cm}$, respectively.

Considering relative dilutions and performance of the control, die-off of *Planktolyngbya* in Patterson Lakes water was insufficient to be confident that draining of the Quiet Lakes into the Patterson Lakes tidal system would not result in spreading the bloom.

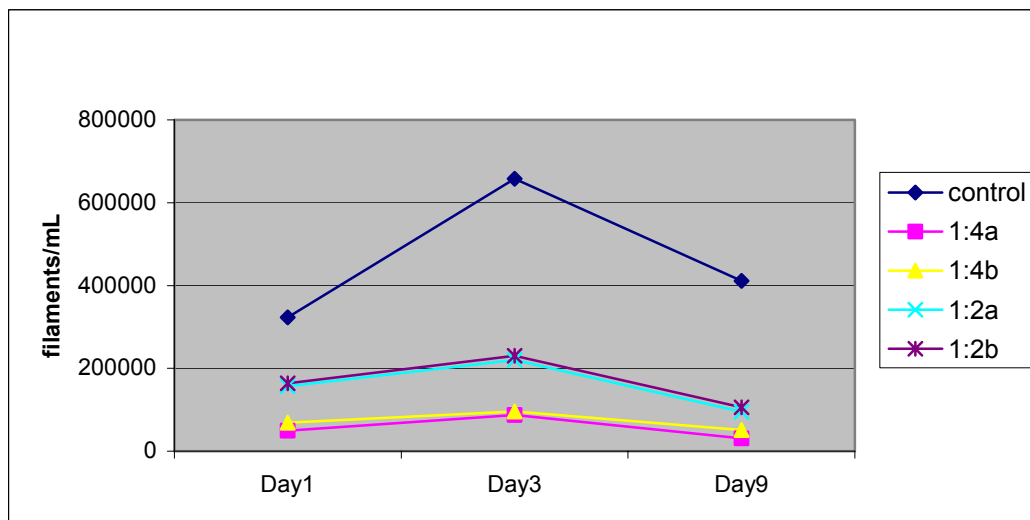


Figure 5: *Planktolyngbya* Survival in Water from Patterson Lakes Tidal System.

'a' and 'b' represent replicates, where 1:4 is a dilution of 100 mL concentrated *Planktolyngbya* from Lake Illawong to 400 mL Patterson Lakes water, and 1:2 is a dilution of 250 mL concentrated *Planktolyngbya* from Lake Illawong to 250 mL Patterson Lakes water. The control was 500 mL concentrated *Planktolyngbya* from Lake Illawong.

Altering Lake Salinity

It was considered that either raising or lowering salinity of the lakes might result in a shift from blue-green algae to a more desirable species. To increase the salinity, water can be pumped from the Patterson River estuary. This option was disregarded

due to results of the saline tolerance experiment and risk of secondary impacts e.g. loss of desirable water plants. The option of lowering salinity has not been pursued due to anticipated difficulty in finding enough good quality freshwater (particularly during a drought) and the possibility that a toxic freshwater blue-green alga would replace *Planktolyngbya* (e.g. *Anabaena*).

Chemical Dosing

EPA was consulted regarding legislation, policy and management of algal blooms within the Quiet Lakes. EPA staff confirmed that, although artificial, the Quiet Lakes are still classified as 'surface waters' under the SEPP (Waters of the Dandenong Valley). This means Melbourne Water cannot discharge pollutants into the lakes (e.g. copper, aluminium, nutrients or dyes). In special circumstances (e.g. significant economical or environmental threat), EPA may provide a temporary permit to discharge pollutants to waterways — but in the case of blue-green algal blooms in the Quiet Lakes, Melbourne Water was told that a permit would not be granted.

All being said, chemical dosing as an algal control technique is an example of poor management. It does not address the cause of blooms and may have undesirable environmental outcomes, e.g. death of fish, plants and other aquatic organisms, the accumulation or persistence of pollutants within sediments (sediment disposal issues as well as environmental issues) and the potential for rapid oxygen depletion resulting in unpleasant odours (as well as a threat to aquatic animals).

PX-700 (Probac Industries)

Suggested by a Lake Legana resident as a potential solution, PX-700 has been off the market for at least 8 years. Probac Industries now market a product called Probac. This is primarily a seaweed extract that provides an injection of nutrients to stimulate anaerobic bacterial growth. It is aimed at treating sewage ponds with the purpose to reduce sulphide production. The manufacturer said that it was not a product aimed at algal control — although there was one anecdotal account that it seemed to help. Probac Industries have no data to indicate that it will control blue-green algae. The cost of a single dosing is around \$22/ML or about \$2,000 for the whole lake.

This technique would not be suitable for Lake Legana primarily because there is no reasonable evidence that it will control the bloom — not to mention our inability under the SEPP to add biostimulants to a waterway with unknown sideeffects. It also does not address the cause of the bloom.

Aerators

Operating a portable aerator to prevent thermal stratification and circulate blue-green algae into deeper and darker water (less light for growth, stress on gas vesicles used for buoyancy regulation), would cost about \$1,000 a day. There are no temporary electric aerators (purchase price is about \$250,000), so a noisy diesel pump would have to be used. It is possible that more than one pump for each lake would be required to provide good mixing of the lakes.

Existing data indicate that the lakes are fairly well mixed and because they are relatively shallow, aerators are likely to have little (if any) benefit. They seem to be

more effective in deep lakes that stratify and where blue-green algae can be mixed into deep and darker water. There are also maintenance and noise issues.

Alternatively, mixing devices could be used to control algal blooms in shallow lakes by vigorously re-suspending sediments to greatly increase turbidity (restricting light availability to algae). This option is not favoured for reasons described in the above two paragraphs, but additionally, aquatic plants are likely to suffer through light reduction and stirring of sediments could ultimately promote blooms (due to increased nutrient release to the water column). It may also cause odours and be considered unsightly by residents.

Activated Carbon

Activated carbon can be used to remove algal toxins, odours and algal cells. It requires an off-stream treatment plant, including filters and alum-dosing to reduce filter clogging. The product can be added to waterbodies in a powder form or used in the treatment process in granular form. There are issues with maintenance of the treatment plant and that the product is explosive. Adding powder to the lake also creates OH&S issues, unsightliness and would be restricted under the SEPP. Length of time required to fully treat the lake is also likely to be long.

Dissolved Air Filtration (DAF)

This technique uses high-pressure air supply to create tiny bubbles that, along with the use of alum, create a floc of algal cells that may be scraped off the water surface. Mechanical requirements and issues of DAF are similar to aerators above, but also require high-grade filtering equipment and subsequent maintenance. Another requirement is an off-stream treatment tank (at least 0.5 ML), which creates a problem about available space. It was estimated to be at least about \$300,000 to set-up the system.

With this technique there are issues about available space for a treatment tank, initial and maintenance costs and the addition of alum to a waterway.

Electropure System (Australian Water Purification)

Suggested by a Lake Legana resident as a potential solution, an Electropure system pumps water into 1,000-3,000 L tanks and treats water using a flocculation/settling technique with aluminium and fine bubbles (similar to DAF). Once treated, water is discharged into either a holding basin or back into the waterbody (along with any residual aluminium). The system requires mains power to run an electric pump, with other components including aluminium plates and filters. It is said to be able to treat up to 60,000 L of water in 24 hours (depending on the quality of the water) — which equates to about 4 years to treat the whole lake (assuming the lake is 100 ML).

Initial costs are about \$30,000 for a 3000 L tank and 1-day installation (+GST). On-going maintenance is daily checking and ensure operating correctness, monthly checks of the pumps and other equipment, and replacement of aluminium plates about every 26 days (\$600 + GST). There will also be electricity costs — quoted at 30 cents for every 3,000 L or \$10,000 to treat the whole lake.

Delivery of the system may take 2 to 4 weeks.

For several reasons this technique is not suitable for the Quiet Lakes. Importantly, the time it takes to treat the lake is unacceptable, but also there is release of aluminium into the lake, and the costs are high. Because causes of the bloom are not being addressed, this technique would need to operate indefinitely.

Air Induced Cyclonic Separation (AICS)

Suggested by a resident, this treatment involves the separation of algal cells from the water by creating a vortex (assisted by microbubbles that are produced by changes in water pressure). Separation of algal cells is similar to a DAF technique. As with DAF, a flocculent (e.g. alum) can be added to improve algal recovery from the water. The treatment process is performed within a specialised treatment tank.

Algal floc formed during the process is removed automatically by a weir and mechanical scraping method, where waste is stored in a separate tank. This is a continuous treatment process, with treated water returned directly to the waterway. AICS will not remove algal toxins or odour, just algal cells — although this distinction is less important for algal taxa such as *Planktolyngbya*, which is a potential risk due to contact irritants.

Requirements are an electric pump (pumping unit approximately 1.2 m x 0.5 m in diameter), 3-phase power for pump, a 3000L/hr treatment tank (approximately 1.2 m x 1.2 m in diameter) and a waste-disposal tank (size will depend on available space and desired cleaning frequency). Similarly with the Electropure System, the anticipated time to treat the whole of Lake Legana is long i.e. about 1,400 days. This is unacceptable, due to the rapid rate that algal cells can multiply.

Assuming no alum dosing is required, cost of the basic system is an initial payment of \$60,000 to \$70,000 (+GST and not including installation, provision for appropriate power source). Power costs were estimated by the manufacturer to be 25 cents/hour or \$186/month. Besides regular cleaning of the waste tank, the only other on-going maintenance was said to be replacement of a part within the pump (about \$60-\$70) every 2-3 years. The manufacturer said that it would be possible to increase the capacity of the system to ML/hr rates, but for example, a 30,000 L/hr system would cost around \$200,000 (ignoring the extra space required for a larger treatment tank). It should be acknowledged, however, that even with this massive upgrade in treatment capacity, it is still estimated to take a long to treat the entire lake i.e. about 140 to 280 days.

In summary, this management approach would be inappropriate because it takes too long to treat the lake, is expensive, and fails to address the cause of the blooms.

IBA Environment Pty Ltd, Bioremediation Technique

This technique was suggested by a resident and involves the use of an algal-specific bacterium to attack the bloom. IBA is based in South Africa and bacteria are imported from France. IBA stated that the bacterium would not impact other aquatic

plants or fish (did not specify any research performed on Australian species). It also stated that they are unaware of the Australian regulations for exporting their product to us (highlighting that it has not been trialed in Australia). Australian Quarantine requires detailed information regarding the product if it was to be imported for the first time (plus an \$180 application fee).

Without being fully aware of risks in local conditions, Melbourne Water is not the appropriate authority to be advocating the use of a biological agent in Australia for the first time. This management technique should not be pursued unless it is endorsed as a potential control option by appropriate authorities (e.g. DNRE, EPA, CSIRO).

Pumping from Lake Legana into Patterson River

Pumping water out of Lake Legana into Patterson River was considered as a management option. Potential risks with this action include spreading the bloom to the river estuary (if not sufficiently flushed), not being able to rapidly re-fill the lake once drained, loss of aquatic macrophytes, and odour problems when lake sediments are temporarily exposed.

Future Actions for Consideration

The following aspects could be considered for future management action:

Develop Planktolyngbya Recreational Alert

Unfortunately there is little information regarding the ecology and toxicology of *Planktolyngbya* and a lack of information regarding public health risk from blue-green algae contact irritants in general. This means that there is a reliance on the recreational guideline of 20,000 cells/mL, without good knowledge of the true recreational risks. It is possible then, that the current guideline is overly conservative (although anecdotal reports of reactions from three individuals swimming in the lakes have been recorded over the last year). It should be noted that quantifying risk from contact irritants is complicated by the likelihood that some people may be more susceptible to reactions than others.

The current recreational guideline of 20,000 cells/mL that DNRE endorses (DNRE 2001) was largely derived using studies from common toxic blue-greens, in particular *Microcystis* and *Anabaena* (WHO 1999). It is difficult to know, therefore, how this guideline applies to *Planktolyngbya* and the actual risk it poses from potential contact irritants.

Planktolyngbya filaments identified within the Quiet Lakes typically have about 20 cells, but because filaments are small and fine, one filament is about 2/5 the biovolume of one *Microcystis* cell (Kumar Eliezer, AWT personal communication). It follows that, 10,000 filaments/mL of *Planktolyngbya* is equivalent to about 4,000 cells/mL of *Microcystis*. When deciding to erect or remove warning signs, at this stage, one filament of *Planktolyngbya* has been treated as equivalent to one cell/mL. This response is based on the recreational alert level and the concept of biovolume being important for risk from contact irritants.

If the recreational alert level is too conservative, and for example was increased to 100,000 filaments/mL, a change in alert level could have a significant impact on the length of time the lakes are not recommended for aquatic recreation. Melbourne Water is currently pursuing involvement in a toxicology study being conducted in 2001 by the Australian Water Quality Centre in Adelaide. The purpose of the study is to better determine the human health risk associated with contact irritants within various blue-green algae. The study, involving human subjects, will ultimately lead to a revision of the current recreational alert level.

Storm Event Sampling

Water quality sampling during and after storm events could be considered to help test the hypothesis that *Planktolyngbya* blooms are triggered by storms, in particular intermittent increases in phosphorus concentrations.

Stratification

More work could be conducted to confirm that the lakes are truly well mixed. Other than repeated sampling efforts like those already conducted, additional work could use continuous monitoring devices. Costs of additional work need to be weighed against anticipated benefit, but is probably a low priority at this stage.

Active Barrier Compounds

Active barrier compounds to lock-up nutrients in sediments may be a management option in the future. This will depend on the outcome of the Monash University research and other related research addressing the performance of active barrier compounds to control blooms and the environmental risks.

Concluding Comments

Managing algal blooms is made difficult due to the complex and diverse nature of aquatic systems. Gaps remain in our understanding of reliable and predictable rehabilitation techniques once a system tends to experience blue-green algal blooms. It needs to be acknowledged by managers and residents, therefore, that the quality of the Quiet Lakes is unlikely to be fixed overnight and may take some time to reach a desirable and sustainable state.

Rehabilitation of the Quiet Lakes may require a combination of carefully considered and related approaches – with a clear and common goal. A clear goal, agreed between Melbourne Water and the residents, is important for directing action and generating shared commitment.

With the goal in mind, it is suggested that people be reminded of the lake history, in particular the relationship of water plants and algal blooms. This means a decision has to be made regarding recreational expectations, particularly in terms of accepting water plants as beneficial. Breen & Muir (1989) and Sainty *et al.* (1990) expressed similar sentiments. If residents acknowledge the importance of plants, it is possible that in the future, a requirement to designate distinct areas for water plants and areas for recreation will be apparent. For example, if harvesting of water plants is seen as essential, then a perimeter could be harvested, leaving the deeper/central areas with healthy macrophyte cover. Alternatively, certain bays could be allocated as no-harvest areas – a decision that residents would need to make. Some literature on amount of

water plants required to prevent phytoplankton-dominated systems exists, and could be reviewed e.g. a minimum bed cover of 50% is required, or 15-30% of the water column occupied by plants. Past and present experience also emphasises the need to closely co-ordinate any harvesting of aquatic plants with carp removal. This will require on-going surveillance of carp populations and, carp removal when appropriate.

The current condition of Lakes Illawong and Carramar seems to be reinforcing importance of water plants in controlling algal blooms, and is providing some encouragement that Melbourne Water's efforts are having a positive impact.

As well as the key actions of water plant re-introduction and carp removal, and the potential benefit of introducing estuary perch, nutrient management is also likely to be important. As suggested by Breen and Connor (unpublished),

- drains that carry the first flush of stormwater run-off should be kept free of blockages and in good working condition to ensure the first flush bypasses the lakes
- residents should be regularly reminded of their role protecting quality of the lakes (e.g. apply fertilisers sparingly, not allowing detergents to drain into the lake, cleaning up after pets, and tidiness with leaf litter and grass clippings).

Residents should also be reminded that the Patterson Lakes Advisory Committee (PLAC) is their formal avenue for raising management concerns with Melbourne Water.

Melbourne Water has not managed the Quiet Lakes algal blooms in isolation. Historical reports and scientific literature regarding algal blooms has been extensively reviewed, opinion has been sought from past managers and appropriate authorities i.e. DNRE and EPA. In addition, regular consultation has occurred with PLAC members and several newsletters have been sent to residents.

Considering the complexity of blue-green algal management, the difficulty in satisfying user requirements and the current progress in Lakes Illawong and Carramar, it is believed Melbourne Water's response to recent blooms has been appropriate.

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Appendix 1: Investigation of *Daphnia* spp. consumption of *Planktolyngbya*

Methodology:

1. Measure EC of Lake Legana and collect a sufficient volume of water to fill three small fish tanks.
2. Measure EC of Edithvale-Seaford Wetlands and collect *Daphnia* spp. (and other zooplankton)
3. Identify and enumerate the level of *Planktolyngbya* and other algal groups in the Lake Legana water (including a replicate)
4. Identify and enumerate zooplankton in the Edithvale-Seaford Wetlands (including a replicate). All zooplankton, other than Daphniidae, are to be identified to family level (or lowest practical level above family). Daphniidae are to be identified to species.
5. Make the following preparations*:
 - I. **One** tank filled with Lake Legana water and 250mL of concentrated *Daphnia* spp. (and other zooplankton) added from Edithvale-Seaford Wetlands
 - II. **One** tank filled with Lake Legana water and 500mL *Daphnia* spp. (and other zooplankton) added from Edithvale-Seaford Wetlands
 - III. **One** tank filled with Lake Legana water as a control
6. After 2 days withdraw two 50mL aliquots from each of the three tanks and enumerate the *Planktolyngbya* population and other algal groups in each aliquot.
7. Repeat Step 7. (e.g. Monday, Wednesday & Friday) until required – but no longer than two weeks.
8. At end of experiment, measure EC of each tank.

* NOTE: all tanks require continuous slight water mixing and adequate light for healthy phytoplankton growth. Water mixing could be achieved using a small pump and airstone.

Appendix 2: Investigation of the Saline Tolerance of *Planktolyngbya*

Methodology:

- Collect one water sample from each of the three Quiet Lakes – Carramar, Illawong and Legana. **Ensure a sufficient volume is collected for necessary preparations.**
- Collect three water samples from Patterson Lakes at sites located evenly around the bay between Swallow Crt and Clematis Crt (Melway 97 H8). **Ensure a sufficient volume is collected for necessary preparations.**
- Measure the EC of the three Patterson Lakes samples and then combine the samples to make a composite
- Enumerate the level of *Planktolyngbya* in each of the Quiet Lakes samples and the composite Patterson Lakes sample
- Using the Quiet Lakes sample with the highest concentration of *Planktolyngbya*, make the following preparations in culture flasks:
 1. **Two** mixtures of 100mL Quiet Lakes sample to 400mL composite Patterson Lakes sample
 2. **Two** mixtures of 100mL Quiet Lakes sample to 200mL composite Patterson Lakes sample
 3. **One** 500mL of Quiet Lakes sample as a control
- Measure the EC of each of the preparations
- After 24hr withdraw 50mL aliquots from each of the **five** preparations and enumerate the *Planktolyngbya* population. Measure the EC of each of the preparations.
- After 48hr withdraw 50mL aliquots from each of the **five** preparations and enumerate the *Planktolyngbya* population. Measure the EC of each of the preparations.
- If required, after one week, withdraw 50mL aliquots from each of the **five** preparations and enumerate the *Planktolyngbya* population. Measure the EC of each of the preparations.