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Lachlan Lower Lakes Water Quality Investigation

Resource Analysis Unit
Central West Region

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EXECUTIVE SUMMARY

The Lachlan Lower Lakes Water Quality Investigation was initiated to determine the effects of storing water in two off-river storages located in the Mid-Lachlan. Lake Cargelligo and Lake Brewster are shallow, eutrophic, turbid and have frequent blue-green algal blooms. Anecdotal evidence from Lower Lachlan landholders suggests that river water quality deteriorates when water is released from these two lakes. It is thought that storing water in Lake Cargelligo and Lake Brewster adversely affects water quality by increasing salinity, turbidity and blue-green algal (cyanobacterial) populations downstream.

The study found that both Lake Cargelligo and Lake Brewster increased electrical conductivity, turbidity, nutrients and blue-green algae in the Lachlan River downstream when discharging. The extent and magnitude of the impact depended on the volume of water released in relation to the volume of water already in the river and the time of year. However, it was found that Lake Cargelligo had a lesser impact than Lake Brewster as a result of its smaller discharge.

Discharges from Lake Cargelligo appeared to increase the salt concentrations in the Lachlan River. Evaporation losses from the Lake Cargelligo system resulted in increasing concentrations of salt in each water body. Though electrical conductivity remained reasonably constant in Lake Cargelligo, the impact on the river depended on both the quantity of the lake discharge and the existing electrical conductivity in the receiving water.

Electrical conductivity in Lake Brewster was higher than that measured in the Lachlan River and the Lake Brewster inlet on the majority of sampling occasions. The impact of this on the Lachlan River depended on Lake Brewster storage levels, the proportion of discharge from the storage and the electrical conductivity of the receiving water.

Releases from Lake Brewster also increased turbidity and suspended solids in the Lachlan River downstream of the outlet. Wind driven resuspension appeared to be a major cause of the turbid nature of Lake Brewster. The fine and very colloidal lake bed was easily resuspended by wave action, settling rates were slow and the lake became increasingly turbid as storage levels decreased.

Nutrient concentrations in Lake Brewster were found to increase with the concentration of suspended sediments. With the disruption of sediments by wind induced wave action, sediments were resuspended, thus re-introducing nutrients into the water column.

The high level of nutrients in both lakes was not only a function of internal inputs from substrate resuspension, but also external sources such as nutrient rich inflows. Both storages have been filled from upstream flooding on the rising arm of the flood hydrograph. Nutrient concentrations are usually greatest during the first stages of a flood event (Cullen *et al*. 1978). Avoidance of the first pulse may reduce the contribution of external nutrient loads.

The reduction of the impact Lake Cargelligo and Lake Brewster had on the Lower Lachlan River water quality could be achieved in a number of ways. These include:

- Ensuring that Lake Cargelligo and Lake Brewster discharges are adequately diluted by river water;
- Reducing residence time of water in Lake Cargelligo storage through flushing;
- Macrophyte re-establishment through maintaining the storage at levels more favourable for macrophyte growth and protecting of bottom sediments;
- Creation of wetland areas within the storages;
- Investigate wind and wave reduction techniques; and
- Prevent or minimise sediment desiccation by maintaining the storage at as high a level as possible.

Both storages had a number of blue-green algal blooms during the study and increased blue-green algal numbers in the river during discharges. Nutrients did not appear to be a limiting factor for algal growth in either lake, with both lakes exceeding recommended nutrient trigger values for the protection of modified aquatic ecosystems. Other variables such as water temperature, pH and wind conditions appeared to have a greater influence on the growth of blue-green algal populations in the lakes. In the case of Lake Cargelligo, blooms may also have been seeded from the two small storages along the inlet channel, Sheet of Water and Curlew Water. These two shallow water bodies are wind protected and blooms have been observed on both storages before blooms are detected in Lake Cargelligo.

There was a clear relationship between blue-green algal numbers and species composition in Lake Brewster and Willandra Weir. The presence of large blue-green populations negatively impacted on overall outflow water quality by increasing turbidity and odour.

To reduce blue-green algal blooms in Lake Cargelligo, options include:

- Taking Sheet of Water off-line to reduce the residence time of inlet water spent in a shallow, turbid water body;
- Use screens to prevent algae and associated scum from leaving the lake;
- Reducing nutrient inputs from the river by avoiding rising arm of flood pulses. This would reduce nutrient loading within the lake over time;
- Frequent flushing of the lake as water temperatures warm. However this may result in an overall deterioration of receiving water through an increase in nutrients and turbidity;
- Reintroducing aquatic macrophytes through replanting and carp removal. Macrophytes would compete for nutrients and improve the overall lake environment as an aquatic habitat; and
- Improve the Lakes Cargelligo and Brewster algal warning and storage operating protocol through better monitoring and water management.

Recommendations for reducing blue-green algal populations in Lake Brewster include:

- Reducing nutrient inputs from the river by avoiding rising arm of flood pulses. As recommended for Lake Cargelligo;
- Reintroducing aquatic macrophytes through replanting and carp removal. This was also an option for turbidity and nutrient reduction;

- The relocation of the outlet channel to avoid wind blown blue-green algal populations. The present location of the outlet channel results in the prevailing winds concentrating phytoplankton populations near the outlet regulator;
- Use screens to prevent algae and associated scum from leaving the lake; and
- As recommended for Lake Cargelligo, improve the Lakes Cargelligo and Brewster algal warning and storage operating protocol through better monitoring and water management.

The preferred approach to implementing this report is to first assess the costs and benefits of these recommendations, and to then prioritise.

The process of rehabilitation of the lakes must be seen in the long-term as it will take a number of years before improvements within the lakes will be seen. However, some strategies, such as improved water management, will have immediate benefits to the Lower Lachlan River.

CHAPTER ONE

INTRODUCTION

1.1 PURPOSE

The Lachlan Lower Lakes Water Quality Investigation was initiated to determine the affects on water quality in the Lower Lachlan River of storing water in Lake Cargelligo and Lake Brewster. Anecdotal evidence from Lower Lachlan landholders suggested that river water quality deteriorated when water was released from the Lower Lakes. It is thought that storing water in Lake Cargelligo and Lake Brewster adversely affected water quality by increasing salinity, turbidity and blue-green algal (cyanobacterial) populations downstream.

There was insufficient data to establish the impacts on water quality from these two storages so, to address this, an intensive short-term study was implemented to assess the relationship between water quality in the Lower Lachlan Lakes and changes in water quality in the Lachlan River.

A total of 21 sites were selected for investigation. These were upstream, downstream and within the lakes. Regular samples were collected to measure nutrients, conductivity, turbidity, suspended solids, algae and other basic water quality variables. Total carbon and total organic carbon were measured at the lake sites and automatic samplers were installed at the lake inlets and outlets to measure suspended solid loads.

This information helped to assess the impacts of the Lower Lakes, and provided information on the causes of water quality deterioration. Once causes were identified, remedial actions could be determined. These included management strategies for improving water quality. Information will also help the Lachlan River Management Committee (LRMC) to establish operational rules for the Lower Lachlan Lakes.

1.2 BACKGROUND

Lake Cargelligo and Lake Brewster are shallow off-river storages that are eutrophic, turbid and have frequent blue-green algal blooms. The storages are located adjacent to the mid-sections of the Lachlan River near the centre of the NSW (Figure 1). Plans of inlet and outlet channels, the storages and their surrounds are detailed in Figures 2 and 3. The dimensions of the storages are listed in Table 1.

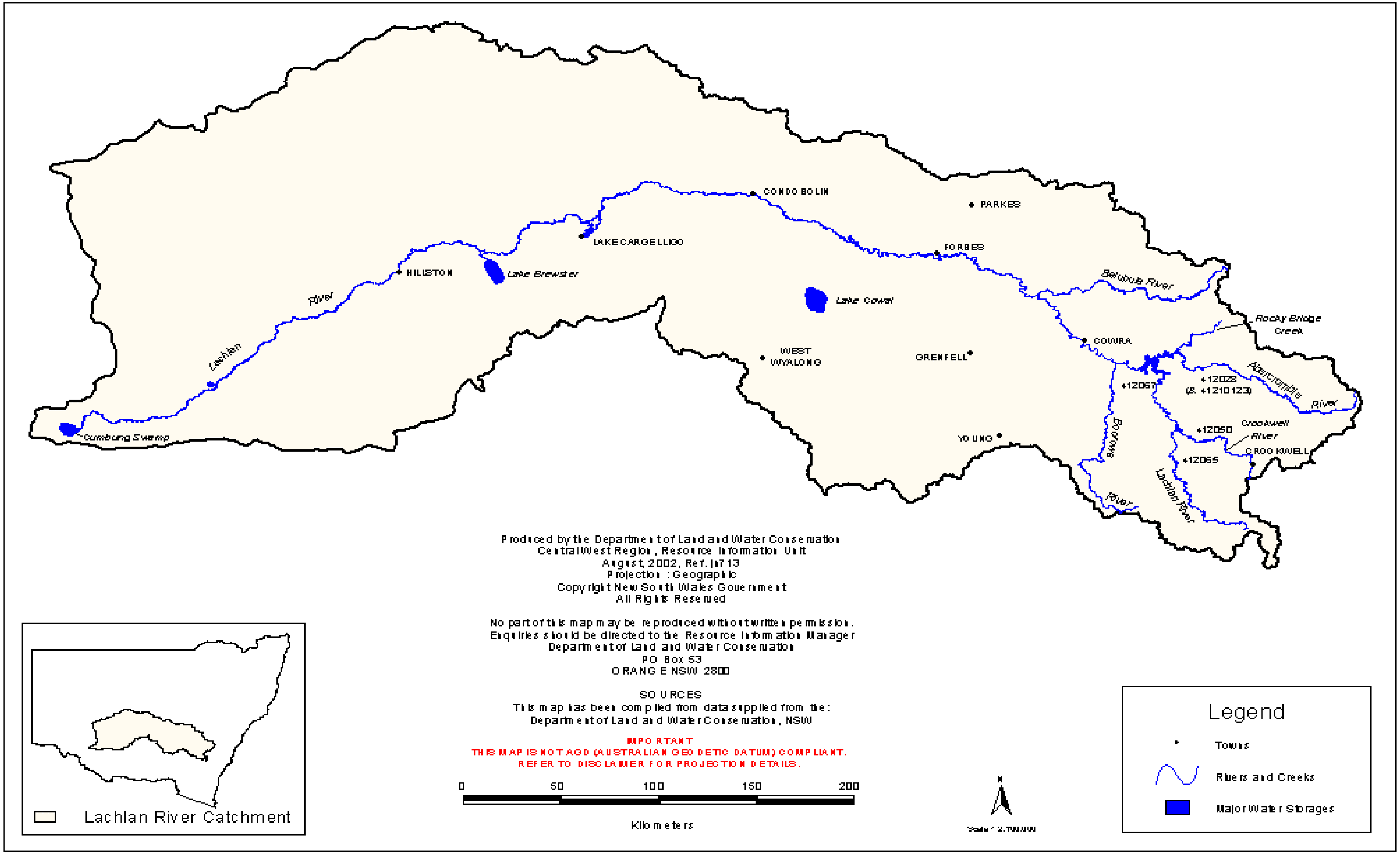


Figure 1 Location of Lachlan Lower Lakes Water Quality Investigation

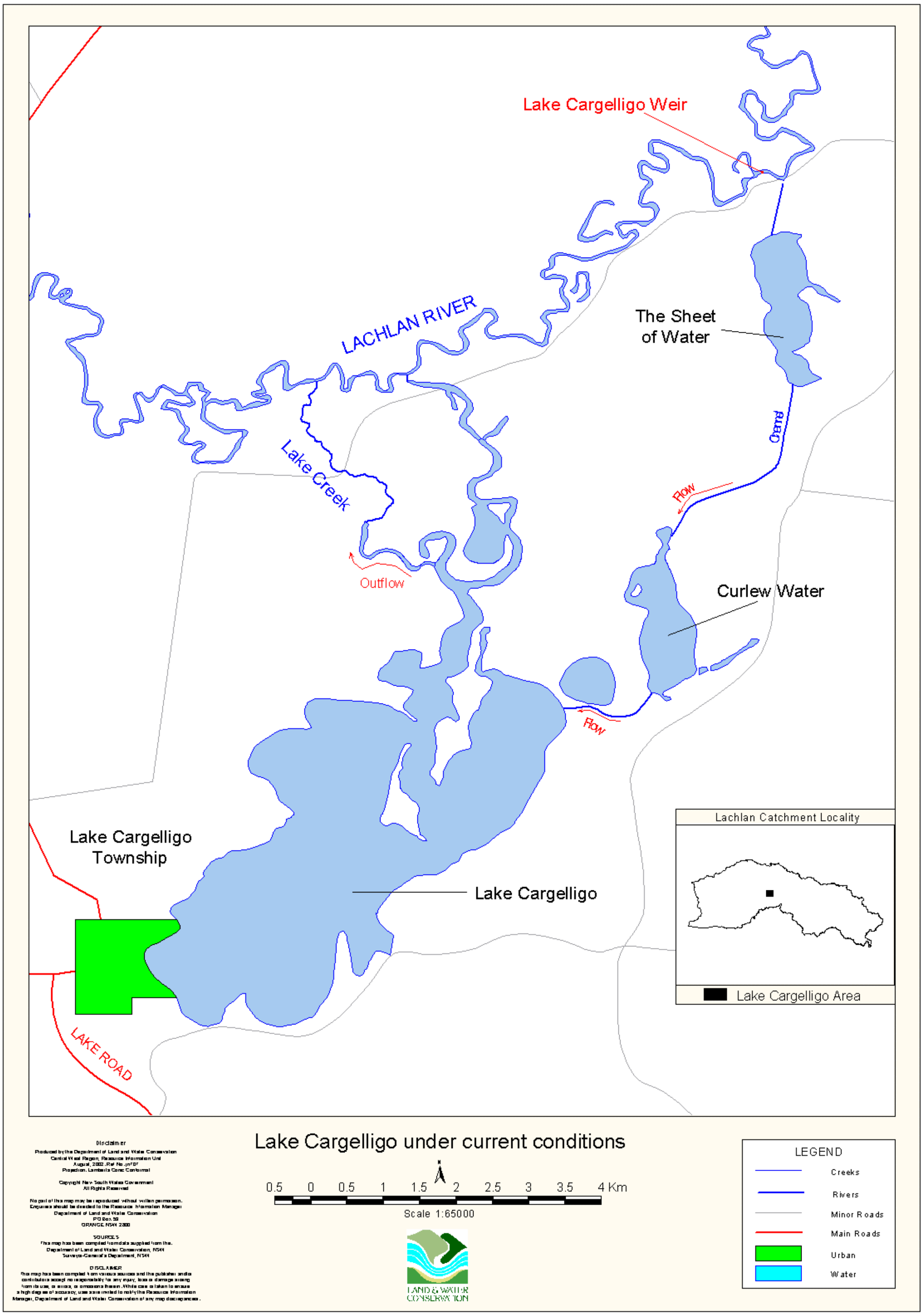


Figure 2. Lake Cargelligo and surrounds

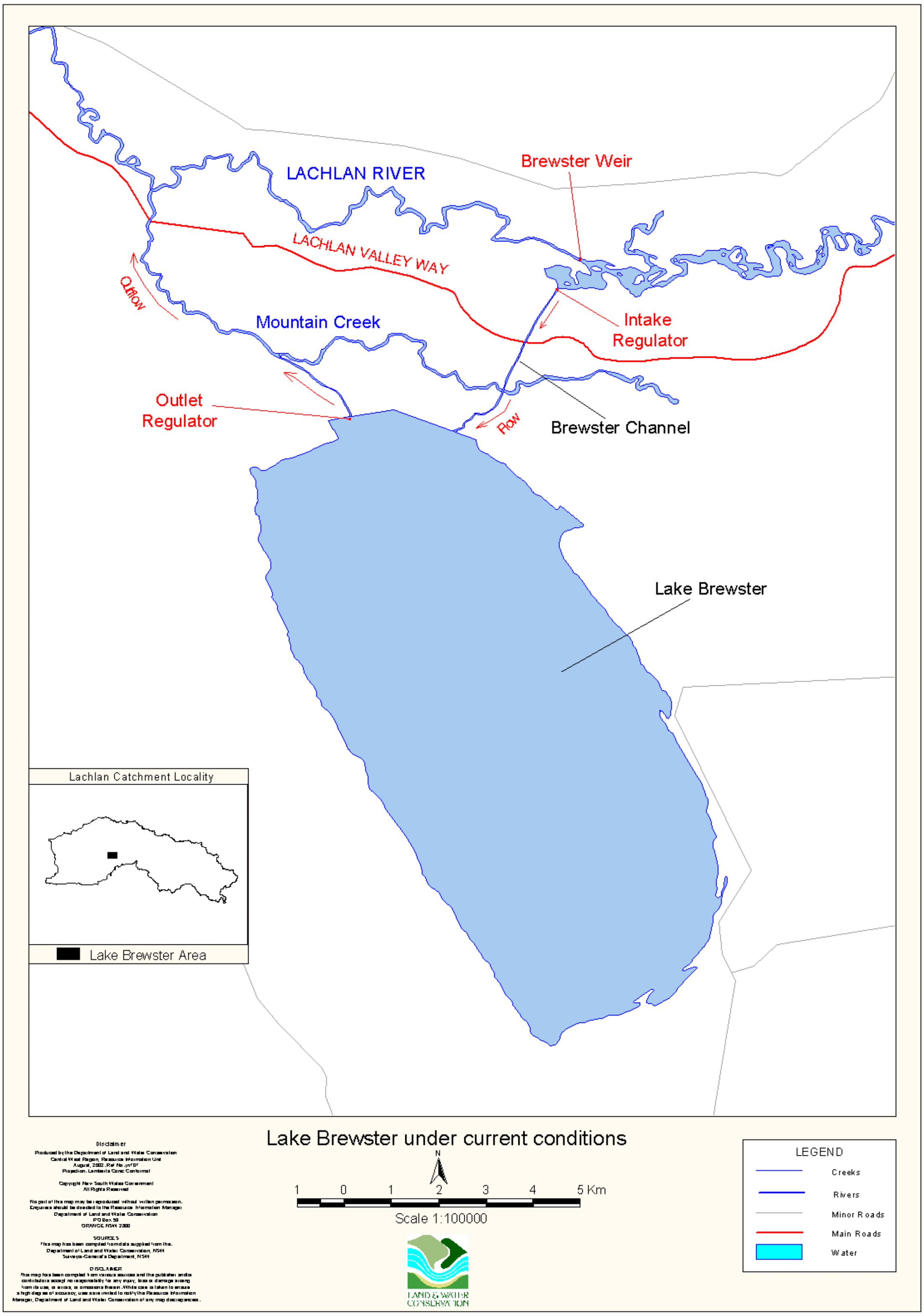


Figure 3. Lake Brewster and surrounds

Table 1 Lake Brewster and Lake Cargelligo dimensions

Lake	Surface area when full (ha)	Maximum storage depth (metres)	Storage capacity (ML)	Useable water (ML)
Lake Cargelligo	**1 500**	**3.7**	**36 000**	**23 000**
Lake Brewster	**6 100**	**3.7**	**153 000**	**133 000**

Both Lake Cargelligo and Lake Brewster (known as Lake Ballyrogan) were originally natural ephemeral lakes. In 1885 landholders around the Lake Cargelligo area built a dam across Lake Creek near Lake Cargelligo. This was the first attempt to control water in the Lachlan Valley. In 1902, the NSW government built a weir and regulator to channel water from the Lachlan River into Lake Cargelligo for storage. During the 1950s Lake Brewster was modified through the construction of Brewster Weir and regulators to control inflow and outflow, levee banks were also constructed to increase storage capacity. These modifications further increased the regulation of the Lower Lachlan. As Lakes Cargelligo and Brewster are downstream of all major tributaries, the operation of filling and releasing from these storages has a large impact on flow in the Lower Lachlan River.

Prior to regulation, the Lachlan River experienced high flows in winter-spring, with flows decreasing over summer and autumn. The Lachlan Catchment State of the Rivers Report (DLWC 1997) provides the pre- and post-regulation flows recorded at Brewster Weir, Booligal and Oxley (Table 2).

Table 2 Pre- and post-regulation flows in the lower Lachlan

	Summer – natural (ML/day)	Summer – regulated (ML/day)	Winter – natural (ML/day)	Winter – regulated (ML/day)
Brewster Weir	955	1080	3070	2140
Booligal	542	340	1020	570
Oxley	549	255	565	295

(Source: Lachlan Catchment State of the Rivers Report, 1997 page31)

Table 2 indicates there is generally less water in the lower reaches of the river under regulated conditions in both summer and winter periods. Historically, the lower river has been operated to provide stock and domestic supplies. However, increasing demand for irrigation supplies in this part of the catchment requires an increased efficiency of water delivery to the Lower Lachlan.

The two lakes serve different purposes in the regulation of the Lachlan River. Lake Cargelligo, generally used as drought storage and a town water supply, is kept at around 70% capacity under normal circumstances. However, it may be drawn down to less than 50% in times of drought. Filling and releasing from Lake Cargelligo is generally a steady process.

Lake Cargelligo also provides a significant recreational facility for the western part of the region. However, the sustained water levels that benefit the community have an environmental cost. Not only have the lake environs changed but the associated hydrological changes have resulted in the development of a persistent, shallow groundwater environment that causes waterlogging and secondary salinisation in some places (Kelly 1992). Seepage and salinisation are particularly evident below the constructed levees associated with the lake.

Lake Brewster is filled rapidly with late winter and early spring flows, usually released from Wyangala. The lake is usually well grassed and subject to grazing at the time of filling. Immediately following filling some areas of the lake appear to turn black as organic matter covering the substrate decays. The water column in these areas remains clear for a few days, then the entire lake becomes turbid and milky as the unprotected substrate is impacted by wave action (B. Orr and P. Little 1999, pers.com.). In summer the lake is often rapidly drawn down as water is released to downstream users. Lake Brewster is almost empty over the summer months, with only the deepest areas in the south-east of the lake retaining water.

Since the early 1980s Lake Brewster has suffered the effects of terrestrial weed infestations. Golden Dodder and Noogoora Burr have been serious threats around the foreshores of the lake and on the lake bed when the water level is low. In 1988, the total infestation covered approximately 2000 ha and the aerial application of herbicide was required to control these weeds.

Lake Brewster is recognised as a wildlife reserve and provides a habitat for waterbirds, particularly pelicans, black swans and cormorants (Table 3). The lake bed is grazed and a small area is occasionally cropped by leasees.

Table 3 Waterfowl of Lake Brewster, 1977-1985

Approx. max. area of inundation	**Number of waterfowl counted**									
	1977	**1978**	**1979**	**1980**	**1981**	**1982**	**1982 (Oct)**	**1983**	**1984**	**1985**
6250 (ha)	15000	10440	3 280	8 650	Dry	10300	9160	Dry	NI	16700
	Late winter-early spring					Late winter-early spring				

NI = Not inspected and assumed to be dry due to previous inspections and climatic conditions

(Source: Water Resources Commission, 1986). Data courtesy J. Brickhill, NSW National Parks and Wildlife)

A conceptual model of Lake Brewster and Lake Cargelligo indicates the complexity of relationships within the lakes (Figure 4). This model shows the physical, chemical and biological variables that interact to affect overall water quality in the storage.

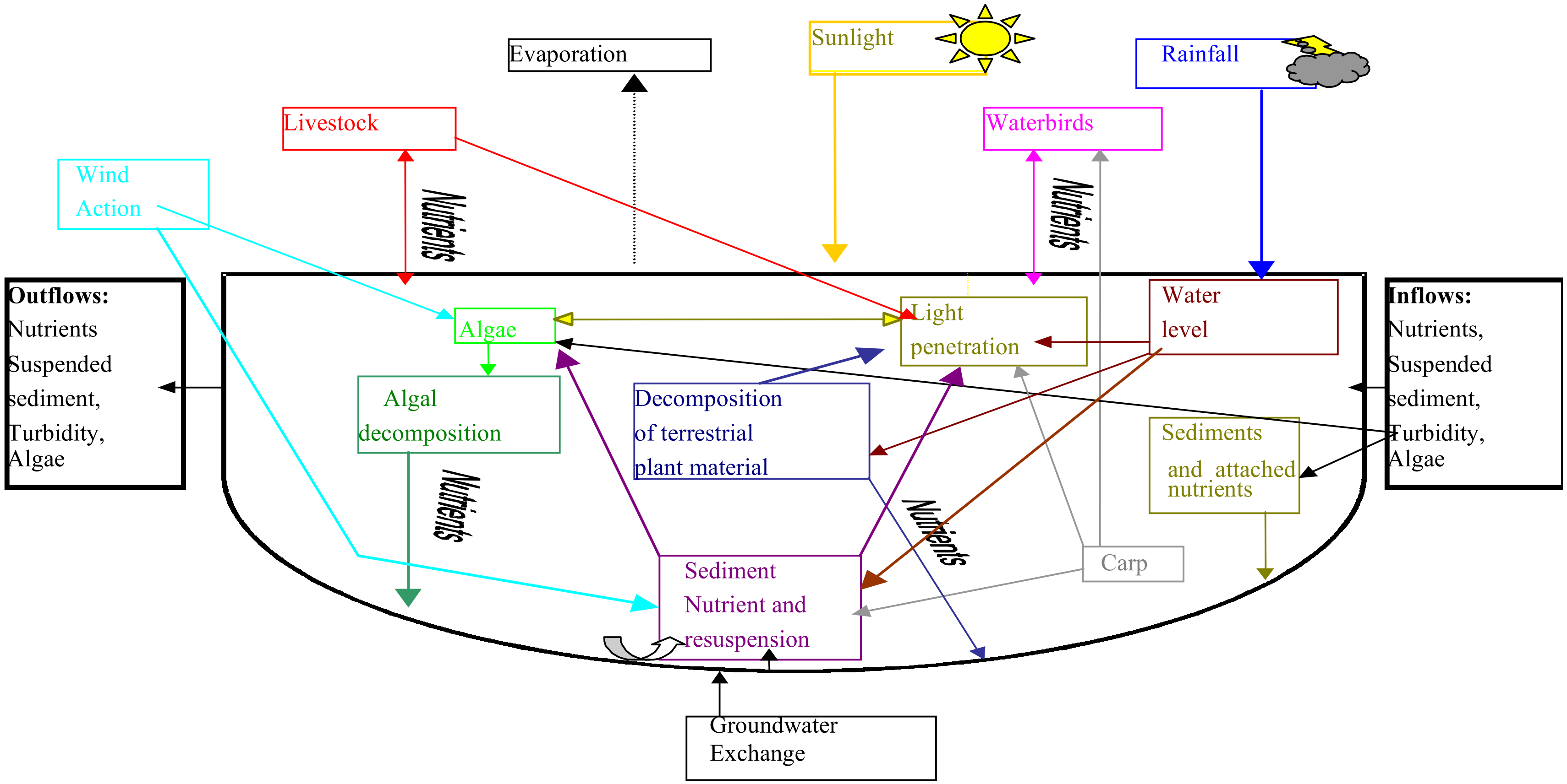


Figure 4 Lake Brewster and Lake Cargelligo conceptual model

CHAPTER TWO

METHODS

2.1 SITES

Twenty-one sites were sampled in and around both lakes. The site locations are illustrated in Fig. 5. Full site names, station numbers and map coordinates are listed in Table 4.

Table 4 Lachlan Lower Lakes Investigation Sites

Site No.	Station No.	Site Name	Easting	Northing	Gauging Station	Auto-sampler
1	412011	Lachlan River @ Lake Cargelligo Weir	448900	6326100	✔	
2	41210161	Lachlan River DS Lake Cargelligo Weir	446650	6323810		
3	412101	Lake Cargelligo Intake @ Regulator	448746	6324545	✔	
4	41210154	Lake Cargelligo Inlet DS Sheet of Water	448850	6321900		
5	41210155	Lake Cargelligo Inlet DS Curlew Waters	447745	6318900		✔
6	41210156	Lake Cargelligo Site A (near inlet)	446500	6318800		
7	41210045	Lake Cargelligo Site B (centre of lake)	443800	6316500		
8	41210157	Lake Cargelligo Site C (near outlet)	445200	6319250		
9	412008	Lake Creek @ Lake Cargelligo Outlet	445661	6320833	✔	✔
10	41210067	Lachlan River @ Murrin Bridge	440050	6325750		
11	412048	Lachlan River @ Lake Brewster Weir	405700	6304200	✔	
12	41210162	Lachlan River DS Lake Brewster Weir	400850	6304940		
13	412102	Lake Brewster Intake @ Regulator	405000	6303600	✔	✔
14	41210158	Lake Brewster Intake @ Lake Brewster	403055	6299850		
15	41210159	Lake Brewster Site A (near inlet)	403000	6297700		
16	41210160	Lake Brewster Site B (open water)	402900	6296500		
17	41210163	Lake Brewster Dead Storage	403838	6294917		
18	412108	Lake Brewster Site C (near outlet)	401600	6301000		
19	41210061	Lake Brewster Outlet Below Storage	401550	6301150	✔	
20	412047	Lake Brewster Outlet @ Bensons Drop	397800	6305600	✔	✔
21	412038	Lachlan River @ Willandra Weir	395300	6309200	✔	✔

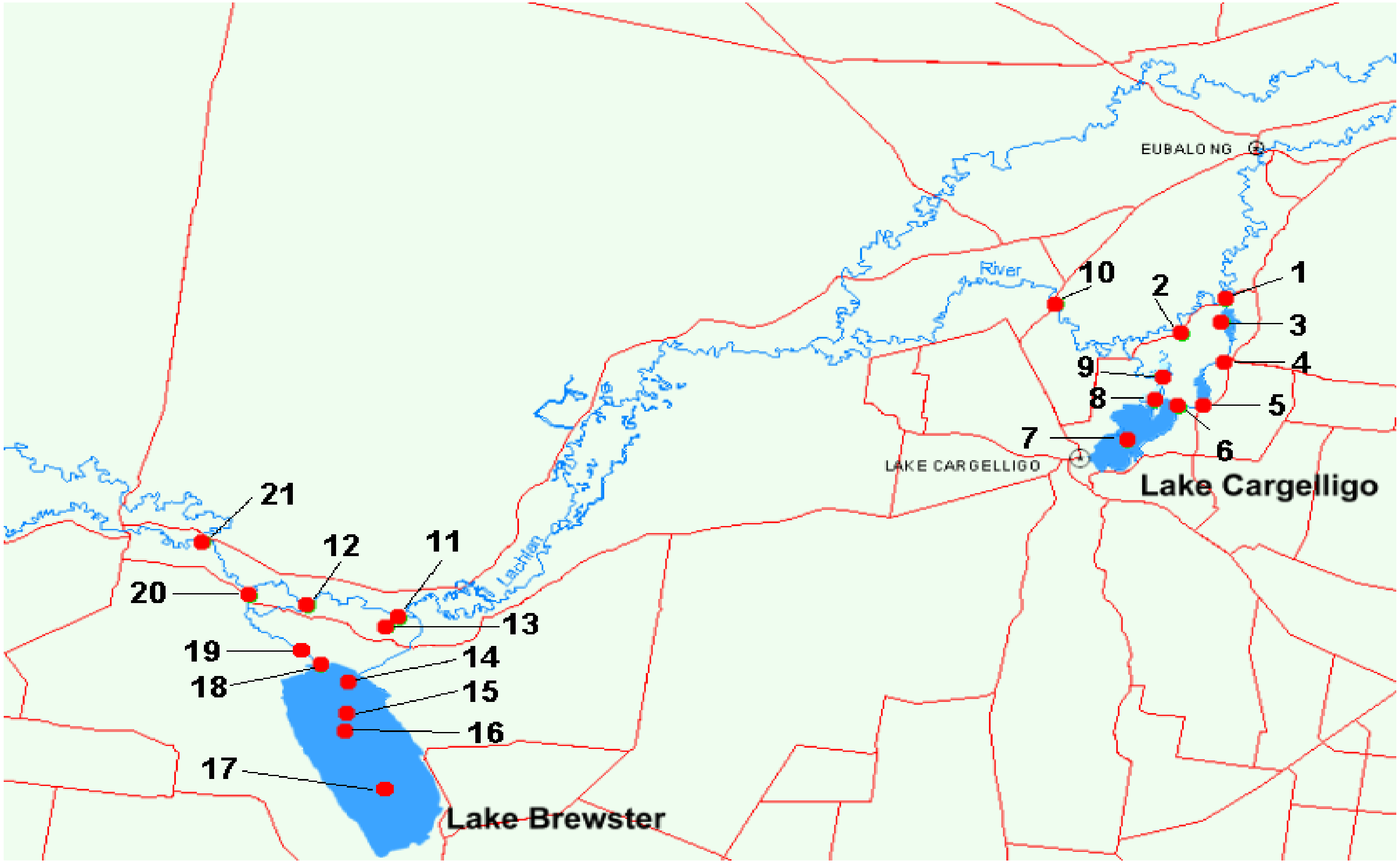


Figure 5 Location of Lower Lachlan Lakes Water Quality Investigations sites

2.2 ROUTINE SAMPLING

During the initial filling of Lake Brewster, in the spring/early summer period (November 1999 to January 2000), weekly algae, suspended solids, turbidity and nutrients including total phosphorus (TP), filterable reactive phosphorus (FRP), total nitrogen (TN), oxidised nitrogen (NOX) samples were collected at the sites listed in Table 4. Collection and analysis of the water samples are detailed in section 2.3.1.

Water quality variables including electrical conductivity, pH, dissolved oxygen and temperature were also collected. The WTW series of field probes and a Hydrolab were used to measure the basic water quality variables and are specified in Table 5.

Samples were collected weekly during the late spring/summer period, then reduced to fortnightly sampling during the autumn/winter period.

Flow was measured at sites indicated in Table 4 using Mindata pressure sensors and data loggers. Data was collected, validated and quality coded by DSNRs Hydrographic staff and entered into the Departments HYDSYS database.

Accompanying routine sampling were a series of intensive water quality measurements on the Lakes. These are discussed below.

Table 5 Instrument details

Instrument	Variable	Units	Specifications
WTW LF320	Electrical Conductivity	µS cm^{-1}	TetraCon® 325, EC Range 1µS cm^{-1} to 2 S cm^{-1}
	Temperature	°C	Temp Range -5°C to 100°C
WTW Multiline P3 pH/Oxi	pH	pH units	pH combined electrode Sentix 41 Range of slope 57.0 – 60.5 mV/pH
	Dissolved Oxygen	mg L^{-1}	Dissolved oxygen probe Cellox 325
Hach 2100P Turbidimeter	Turbidity	NTU	Range:0-1000 NTU Accuracy: ±0.2% of reading Resolution: 0.01 NTU
Li-Cor Light Meter	Photosynthetically Active Radiation	µmol S^{-1} m^{-2}	LI-192SA underwater quantum sensor. 400-700nm quantum response. In 'air' calibration = -262.47, in 'water' calibration = -346.46. Accuracy: ±0.4% of reading
Hyrdolab Multiprobe	pH	pH units	pH range: 0 to 14 units, accuracy ±0.2 units
	Dissolved Oxygen	mg L^{-1}	DO range: 0 to 20 mg L^{-1}, accuracy: ±0.2 mg L^{-1}
	Electrical Conductivity	µS cm^{-1}	EC range: 0 to 100 mS cm^{-1}, accuracy: ±0.1 % of range
	Turbidity	NTU	Turbidity range: 0 to 1000 NTU, accuracy: ±5% of range
	Temperature	°C	Temperature range: -5 to 50°C, accuracy: ±0.10°C

Knowledge of stratification in both Lake Cargelligo and Lake Brewster was limited. It was thought that both waterbodies were too shallow and exposed to wind action to stratify over the long-term. However this assumption needed further investigation. Temperature, oxygen and salinity profiles were used to identify any stratification in Lake Cargelligo and Lake Brewster and to assess the extent to which any vertical physical and chemical stratification occurred. Temperature, dissolved oxygen, and electrical conductivity profiles were taken at lake sites on a weekly basis during late spring and summer, fortnightly during autumn and winter. On each sampling occasion a Hydrolab Multiprobe was used. Specifications of the Hydrolab are detailed in Table 5.

Light availability may also be an important factor affecting the increase of cyanobacterial blooms and the decline of macrophytes in Lake Cargelligo and Lake Brewster. The assessment of turbidity and light penetration was required to determine the depth of light penetration in the lake waters and the relationship between light penetration and turbidity. A Hydrolab fitted with a turbimeter was used to measure turbidity just below the water surface and every 0.5 m below that, in both lakes (Table 5). A Li-Cor light meter was used to measure Photosynthetically Active Radiation (PAR) (Table 5). Measurements were taken in 'air' and in the water at 0.05, 0.10, 0.20, 0.30, 0.50 m and every 0.5 m below that. The profiles measured down-welling irradiance and each reading was averaged over 30 seconds, and taken in constant light conditions.

It is thought that water released from the Lower Lakes increased river turbidity and suspended solids. To quantify suspended solids loads entering and leaving the Lower Lakes, and possible affects on downstream water quality, automatic samplers were installed at the inlet and outlet of Lakes Cargelligo and Brewster for collection of suspended solids samples.

Turbidity and suspended solids were measured from samples taken daily or every second day from the automatic samplers during inflows and outflows to and from the lakes. The cause of turbidity in Lake Cargelligo and Lake Brewster was largely unknown. To determine causes of turbidity to the two lakes, it is necessary to quantify the inorganic and organic components of suspended solids. Total organic carbon (TOC) is a direct expression of total organic content. If total carbon (TC) and TOC are measured separately, an inference can be made between the percentage of particulates that are organic or inorganic.

2.3 WATER SAMPLING PROCEDURES

2.3.1 Water sample collection

Water samples were collected in 250 mL polyethylene bottles which were rinsed twice in situ. The sample was collected at 0.25 m depth by plunging the bottle top down to the required depth, then rotating the bottle and allowing it to fill. The analysis of FRP and NOX required the filtration of the sample through a 0.45 µm cellulose acetate filter. This was performed in the field within several hours of collection by using a transportable electric pump and Sartorius filtration equipment. Lugols was added immediately to algal samples. All samples were chilled to around 4°C immediately following collection. Nutrient samples were frozen within 8 hours of collection.

Total and organic carbon samples were collected in acid washed 1 L amber glass bottles which were sealed with aluminium foil before and after sample collection.

Algal, suspended solids, nutrient samples and total carbon samples were transported by courier to the Water Environment Laboratory for analysis. Samples were analysed using Standard Methods (APHA, AWWA & WEF 1998).

2.3.2 Diurnal Water Quality Monitoring Methods

Diurnal changes in water quality were measured in Lake Cargelligo using Minisonde Water Quality Multiprobes. Probes were strung from a floating pontoon at specified depths down the water column. A modified esky housing the batteries and cables was secured to the top of the pontoon (Figure 6).

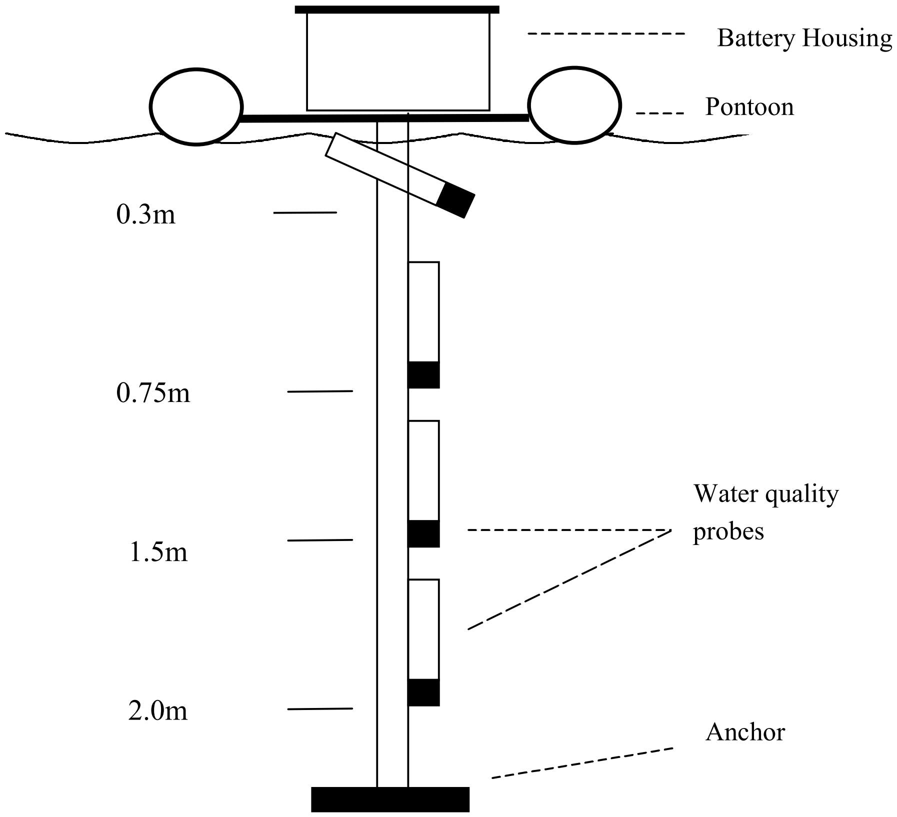


Figure 6. Diurnal water quality monitoring station

Minisonde Water Quality Probes were calibrated according to manufacturer instructions and programmed to up-load data at 30-minute intervals. Temperature, dissolved oxygen, electrical conductivity and pH were collected. Ambient weather data was collected from the Lake Brewster weather station (approx. 40km to the south-west of Lake Cargelligo). Although a Bureau of Meteorology (BOM) weather station is located at Lake Cargelligo that records temperature and wind patterns twice daily, the Lake Brewster station data was used for this report because it records once every hour. Lake Brewster weather station data was checked against Lake Cargelligo BOM data to ensure comparability.

Sampling was conducted on three separate occasions, 24th to the 27th October 2000, 5th to the 8th of February 2001 and 12th to the 14th of February 2001.

2.3.3 Lake Brewster Sediment Study

The resuspension of sediments by wind induced wave action is thought to be the major contributor of suspended material in Lake Brewster. The sediment study examined the lakebed sediment properties of Lake Brewster to help identify target areas for rehabilitation and management.

A topographic map of Lake Brewster was divided into three (North, Mid and South) sections (Figure 7). Five random points were selected from each section using a random number table. Sediment samples were collected using an auger (diameter 10 cm) taken to a depth of 20 cm. Particle Size Analysis (PSA) was conducted at DSNR's Scone Research Centre.

In conjunction with the sediment study a suspended solid settling experiment was used to estimate how long suspended material took to settle in the absence of wave action. Turbidity in Lake Brewster and, to a lesser degree, Lake Cargelligo may be a factor of internal sediments being resuspended through wave action. To determine whether wave action is a primary factor in the resuspension of solids or the solids do not sink, lake water was allowed to settle in the laboratory.

Samples were collected over several months, 14 June, 25 July, 5 September and 3 October 2000, to cover periods of varying wind velocity and direction. 1 L sample bottles were rinsed with lake water then filled 0.25 m below the water surface from routine lake sampling points. Samples were chilled and transported back to the laboratory, well-mixed and placed into an Imhoff cone. Turbidity and settled material levels within the cones were measured every 24 hours for a period of 3 days.

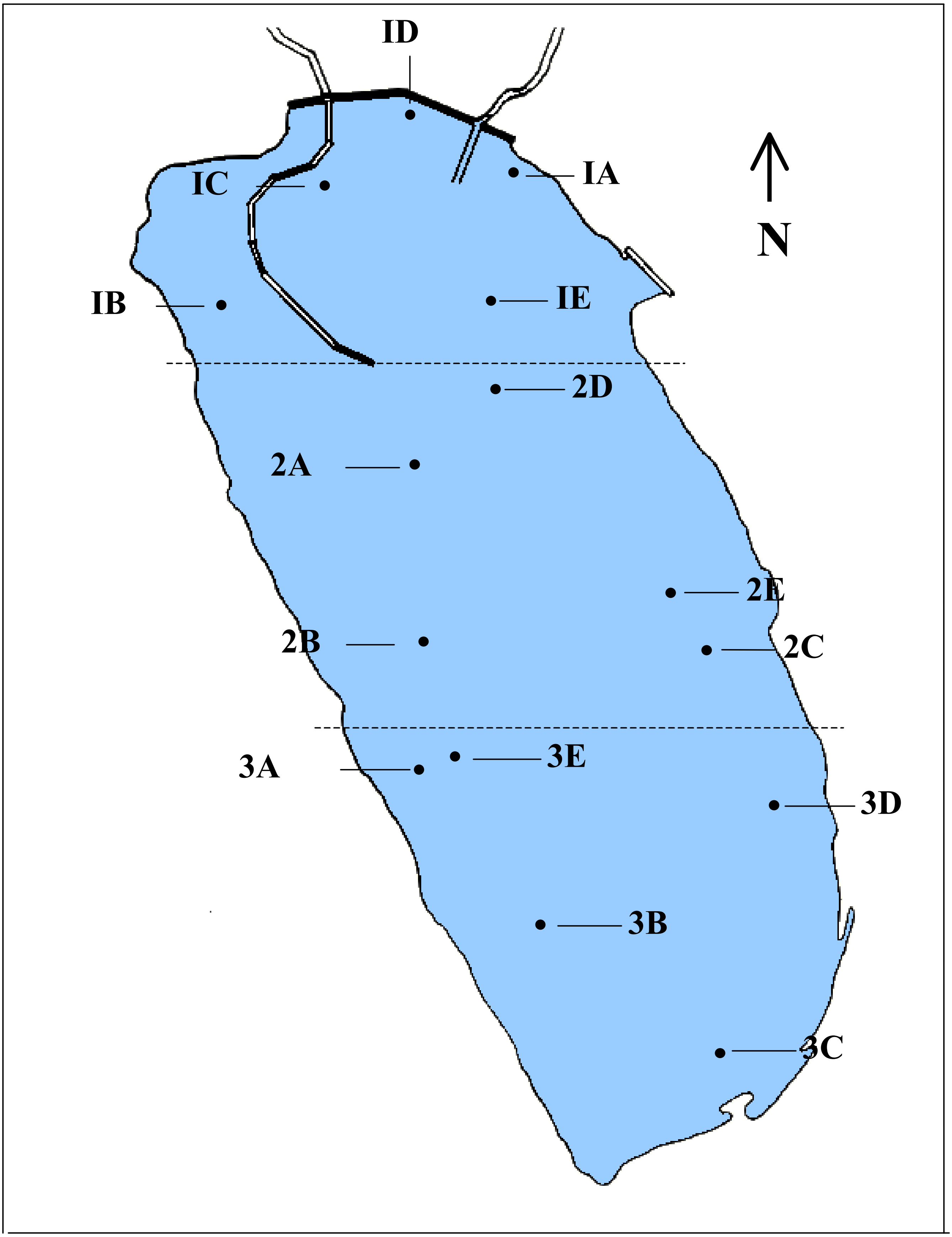


Figure 7. Lake Brewster sediment sampling sites

2.3.4 Macrophyte Mapping

Many of the problems associated with both Lake Brewster and Lake Cargelligo may be related to a lack of riparian and aquatic vegetation protecting the bottom and riparian sediments from inundation and wave action. Remote sensing imagery was used to attempt to map historical and remaining submerged vegetation in Lake Brewster.

Remote sensing images were obtained through the Australian National Mapping Agency. Current and archival landsat images were obtained covering all 8 bands. Unfortunately the necessary ground-truthing required to verify results from the imagery was not possible as Lake Brewster did not fill in 2001/2002. Therefore interpretation of the images is limited.

2.4 STATISTICAL ANALYSIS

The distribution of data was tested using summary statistics. Descriptive graphical techniques were used to summarise the data and compare variables. All box plots display the median (the line within the box), 25th and 75th percentiles (the boundary of the box), 10th and 90th percentiles (the whiskers above and below the box) and the 5th and 95th percentiles (the small circles above and below the whiskers). The blue-green algae box plots also display mean lines which are small dotted horizontal lines. The multiple cross-correlations that occurred in the data made more sophisticated statistical techniques inappropriate.

Where appropriate, flows, algal densities and water quality variables were log-transformed (base 10) and correlations performed.

Multivariate analysis of log10 transformed blue-green algal community data required the calculation of dissimilarity using Bray and Curtis dissimilarity measure. Ordinations using Semi-strong-hybrid (SSH) multi-dimensional scaling were then performed using the dissimilarity values to create patterns of association amongst sampling sites and occasions. The ordinations were summarised by plotting the ordination scores of each axis against each other. The closer the samples are in ordination space, the more similar is their community structure. All multivariate analysis was performed using PATN (Belbin 1992).

CHAPTER THREE

RESULTS AND DISCUSSION

3.1 DIURNAL WATER QUALITY STUDY

3.1.1 Lake Cargelligo

Diurnal water quality monitoring at Lake Cargelligo was initiated to compliment the routine sampling of the Lower Lakes Water Quality Investigation. Routine water quality monitoring is an effective way to study water quality trends on a large scale, however routine sampling may not detect daily changes in water quality. Continuous water quality monitoring data provides information on water quality variables on a short-term scale. Three diurnal water quality monitoring projects were scheduled to record daily temperature and other physical water patterns at specific depths.

Thermal stratification of waterbodies generally occurs when flows are low, ambient temperatures high and when conditions remain calm and sunny for extended periods. The temperature of surface waters increase rapidly, while deeper waters remain cool, the temperature gradient down the water column is known as a thermocline and the water is said to be thermally stratified. Turbid lakes, such as Lakes Cargelligo and Brewster, absorb heat closer to the lake surface, further enhancing temperature and density differences with water depth.

A temperature difference of greater than 1^{o}C between surface and deeper water is generally given as an indicator of thermal stratification. Smaller temperature differences can also inhibit mixing, especially in warmer waters where density differences are much greater than in colder waters. A thermocline can act as barrier restricting vertical movement of physical, chemical and biological processes, therefore impacting upon in-lake processes. These processes may include:

- deoxygenation of the lower layer of water in a lake (known as the hypolimnion) creating an unsuitable environment for fish and macroinvertebrates (Moss 1998);
- changes to nutrient release patterns through the re-mobilisation of phosphorus with the onset of anoxia (Chapman 1992), and
- alteration of sediment settlement rates (Scheffer 1998).

Thermal stratification (temperature difference greater than 1 ^{o}C) was observed in Lake Cargelligo on 20 of 70 routine sampling occasions (Figure 8) with 65% of these events occurring between the months of November and February (Table 6). The greatest temperature difference between surface and water at 2 m below the surface was 4.51^{o}C in early February 2002. During the cooler months the water column was well mixed, temperature changes at all depths followed that of ambient temperatures, as was recorded in the first diurnal sampling in October 2000 (Figure 9).

Warmer temperatures during early February 2001 were expected to initiate thermal stratification in the storage but this was initially prevented due to strong winds (Figure 10). As winds eased following the 7th of February 2001, stratification of the water column was established. A temperature difference of about 3^{o}C between surface and bottom waters was recorded at 16:00 hours, this was the greatest recorded temperature difference (Figure 10). The thermocline began to break down as surface temperatures cooled and deeper waters warmed until a homogenous water column was established at midnight. A similar pattern of stratification began as temperatures increased the following day (Figure 10).

Under stratified conditions the hypolimnion becomes isolated from photosynthetic oxygen production. Oxygen concentrations in the hypolimnion fall as bacteria and bottom dwelling organisms respire, also producing carbon dioxide (Moss 1998). Oxygen consumption in the hypolimnion is exacerbated by the continual accumulation of dead phytoplankton cells, detritus, animal faeces and corpses and associated bacteria. The depletion of oxygen in the hypolimnion limits available oxygen required by fish, macroinvertebrates and other bottom dwelling organisms for respiration. The motile organisms can relocate to more suitable environments but sessile organisms are stranded.

Unlike deeper or more protected storages, where a thermocline can persist for weeks, months or be semi-permanent, Lake Cargelligo is shallow and exposed enough to allow mixing of water and prevent permanent stratification. While some degree of stratification occurs during the day as ambient temperatures increase, the thermocline is rapidly broken with the onset of cooler night temperatures. Wind driven wave action also acts to destabilise the water column, preventing persistence of a thermocline.

The impact of thermal stratification upon dissolved oxygen concentrations measured over the diurnal study period is shown in Figure 11. At times when the water column is well mixed, dissolved oxygen concentrations were similar at all depths (Figure 11). Diurnal fluctuations occurred in-line with temperature variation (cooler water can hold more dissolved oxygen) and algal activity (while photosynthesising algae release oxygen to the water). With the onset of stratification (12:00, 7/02) dissolved oxygen concentrations at the surface increased while the isolated deeper water decreased but did not approach anoxia (Figure 11).

When bottom waters are anoxic, interstitial phosphate can diffuse to the overlying water (Chapman 1992). The release of phosphorus from sediments has major water quality implications and it can lead to algal bloom development. Phosphorus is often the limiting nutrient for algal growth and, under the appropriate conditions, the release of phosphorus from sediments can initiate an algal bloom. If the water column is stratified, the release of phosphorus from the hypolimnion to surface dwelling algae is delayed until the water column is remixed, but can still have major impacts upon subsequent algal growth. The release of high nutrient waters from storages can also impact upon downstream river ecology.

Anoxic conditions were rarely detected in Lake Cargelligo during the current study, the lowest dissolved oxygen concentration being recorded on the 18/2/02 (1.16 mg/L during routine sampling) (Figure 12). The low dissolved oxygen concentration was measured at 3.5 m in the centre of Lake Cargelligo when thermal stratification was also detected (Figure 12). This reduced oxygen concentration may accelerate phosphorus release from sediments, the associated phosphorus release is discussed in the nutrient section (see section 3.4).

Table 6. Number of days when a temperature difference of greater than 1^{o}C was detected between surface and 2m water in Lake Cargelligo, 1999 - 2002.

Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
5	2	1	1	2	1	0	0	2	0	3	3

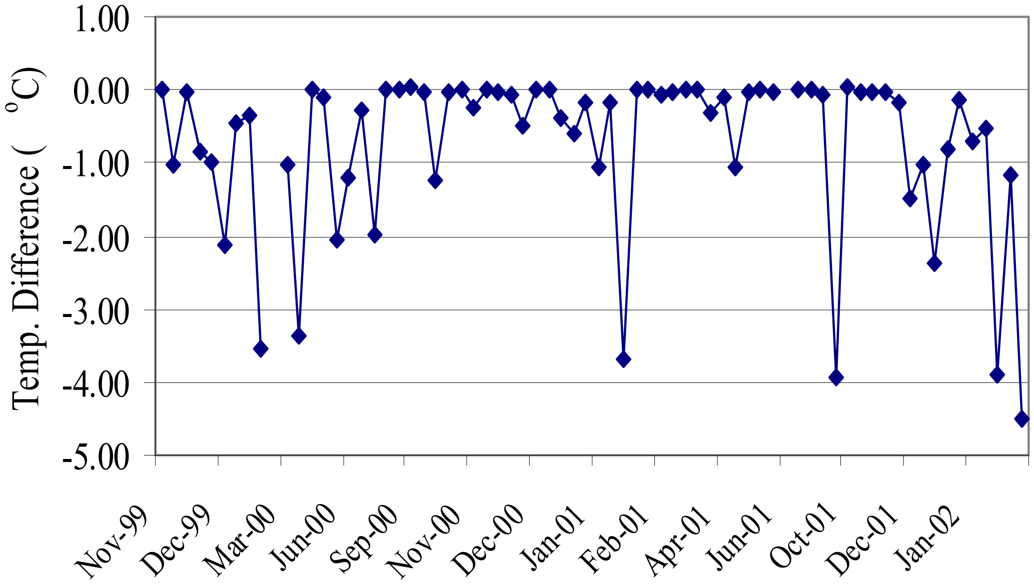


Figure 8. Temperature difference between surface (0.05m) and 2m depth, Lake Cargelligo Site B, 1999 – 2002.

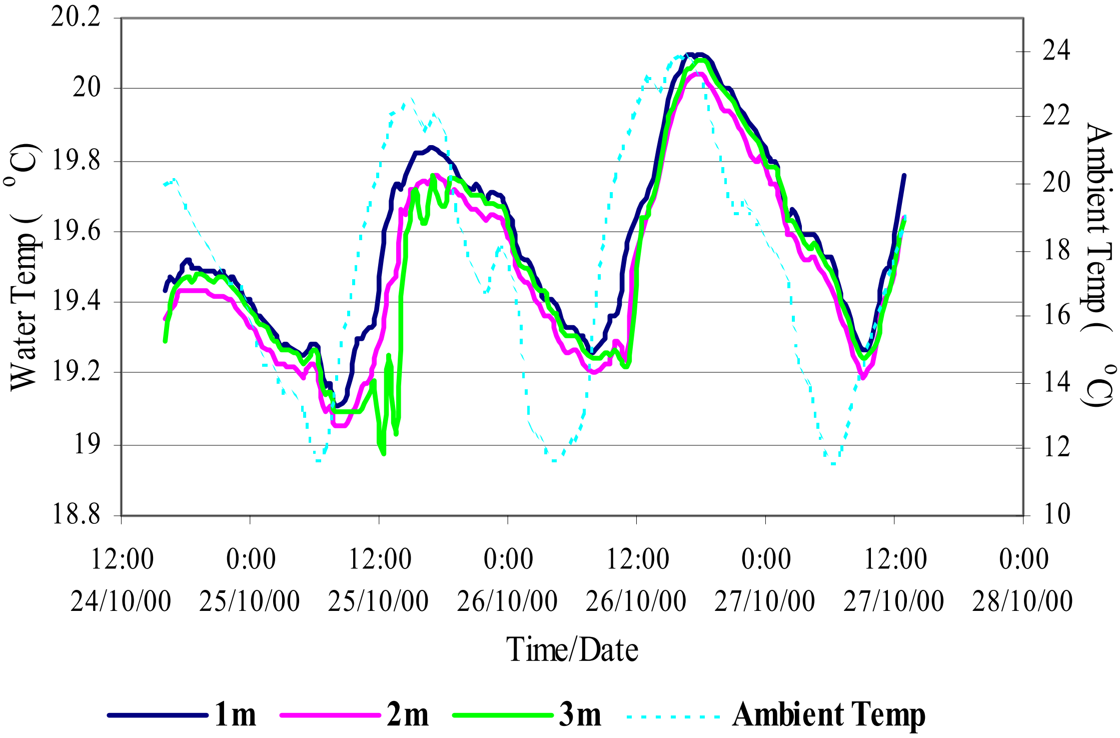
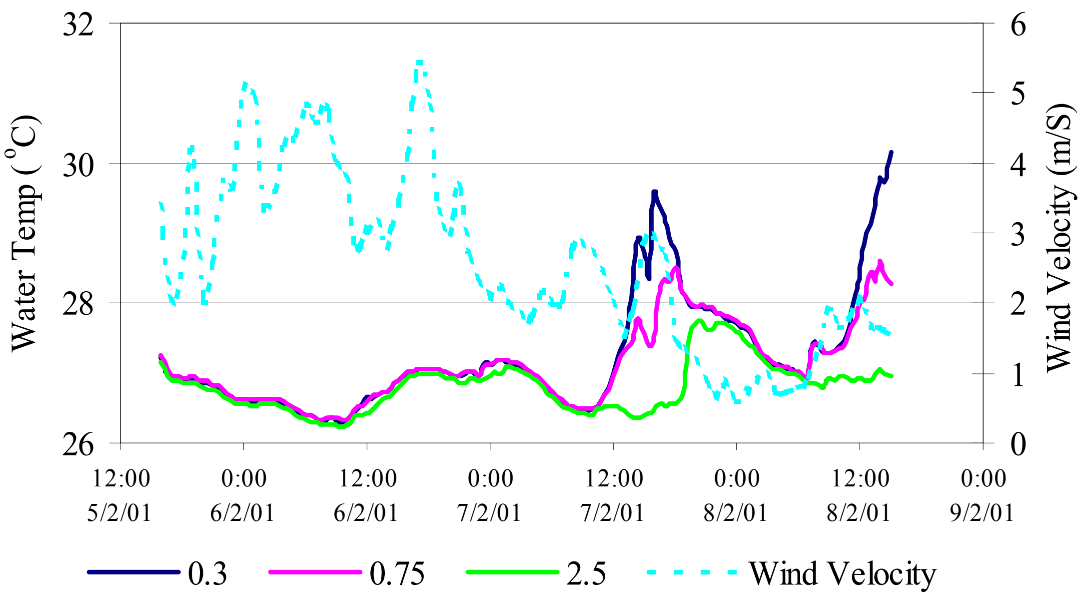


Figure 9. Lake Cargelligo Site B diurnal temperature fluctuations, 24 October 2000 to 28 October 2000.

a) Wind Velocity



b) Ambient Temperature

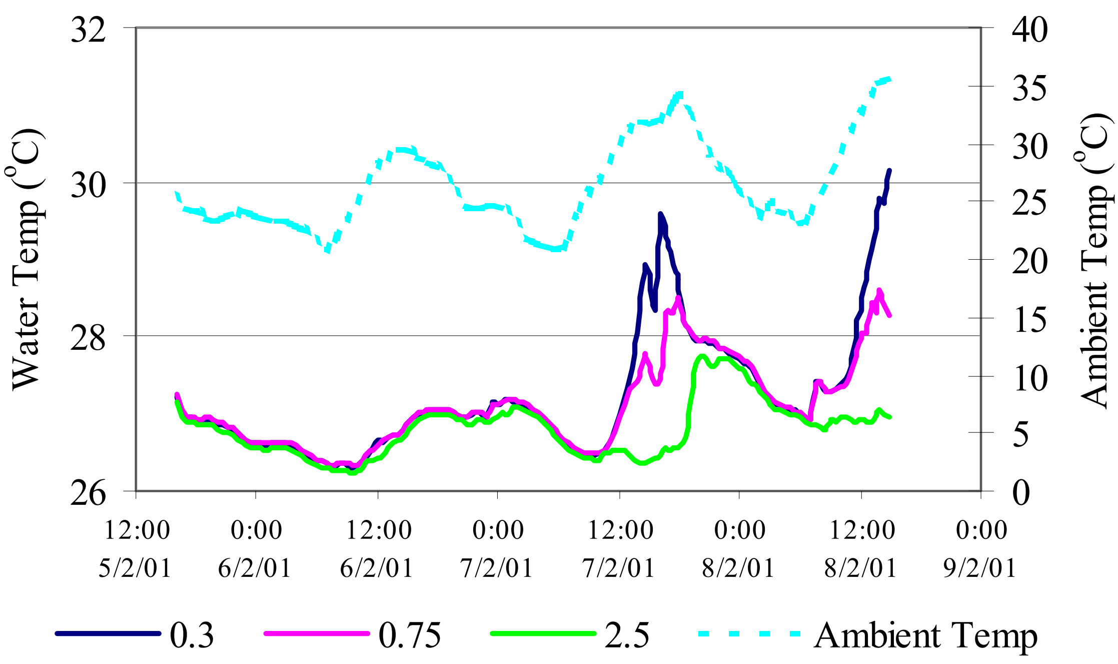


Figure 10. Diurnal temperature profile and (a) wind velocity, (b) ambient temperature at Lake Cargelligo Site B, 5 February – 9 February 2001.

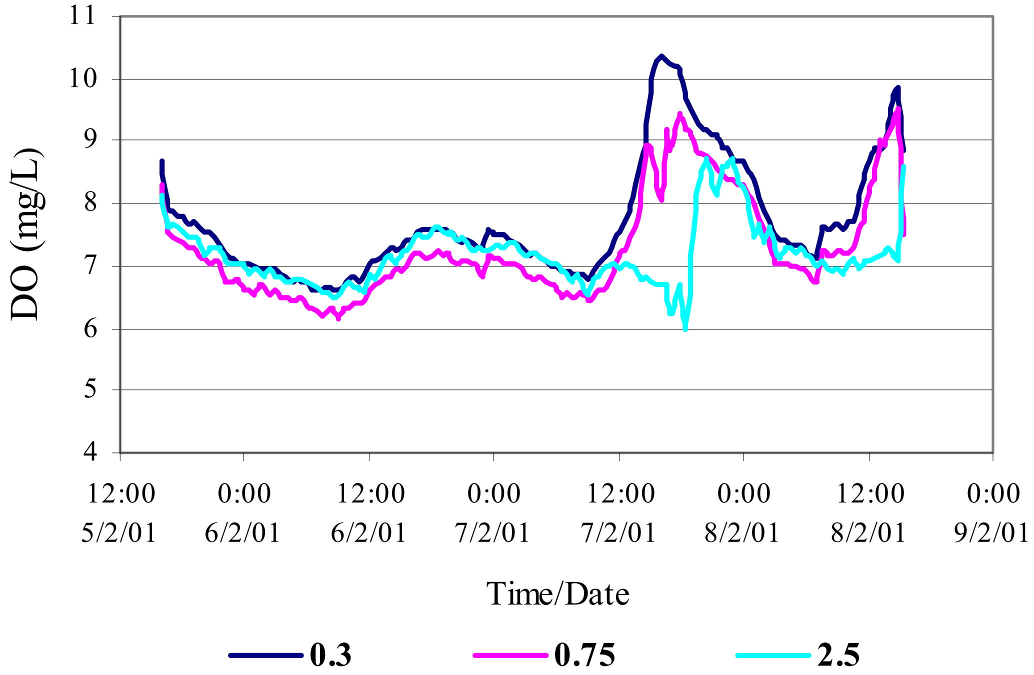


Figure 11. Diurnal dissolved oxygen concentrations at depths 0.3, 0.75 and 2.5 metres at Lake Cargelligo Site B, 5 February – 9 February 2001.

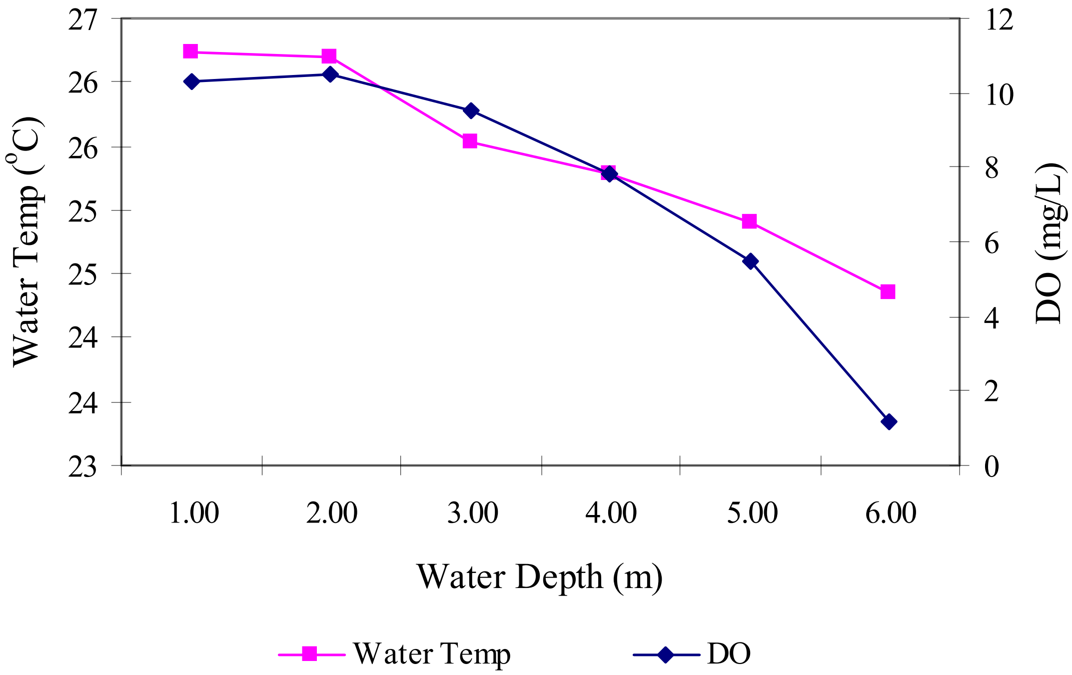


Figure 12. Dissolved oxygen and temperature profile at Lake Cargelligo Site B, 18 February 2002.

3.1.2 Lake Brewster

Lake Brewster was predominantly impacted by south-westerly winds that run the length of the storage (see Section 3.3.3.2). Due to the exposed nature of the storage, wind driven wave action is likely to be a major force year round. This appears to result in a well-mixed water column, with the rapid destabilisation of any stratification. Figure 13 shows the temperature difference (^{O}C) between surface water and at a depth of 1 m.

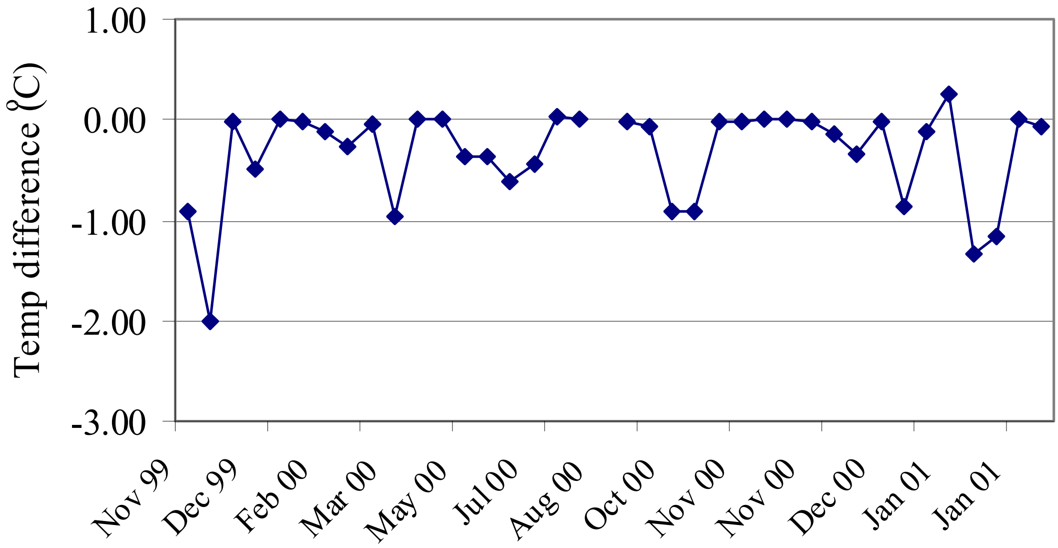


Figure 13. Difference in temperature between depth 0.05 and 1.0 m at Lake Brewster site B, 1999 - 2001.

Figure 14 shows the temperature difference between surface water and water at a depth of 2 m at Lake Brewster Site B. During the summer months, stratification occurred on a regular basis (9 times out of 24 sampling occasions - 37.5%). Lake Brewster is generally full at the beginning of summer and low in winter due to irrigation supply and, as a result, sampling at 2 m during winter was not possible. This lack of data over winter is reflected in Figure 14. It is expected, however, that the lower ambient winter temperatures would not promote the establishment of a thermocline. Anaerobic conditions were recorded in the hypolimnion of Lake Brewster, the possibility of phosphorus release is discussed in the nutrient section (see section 3.4).

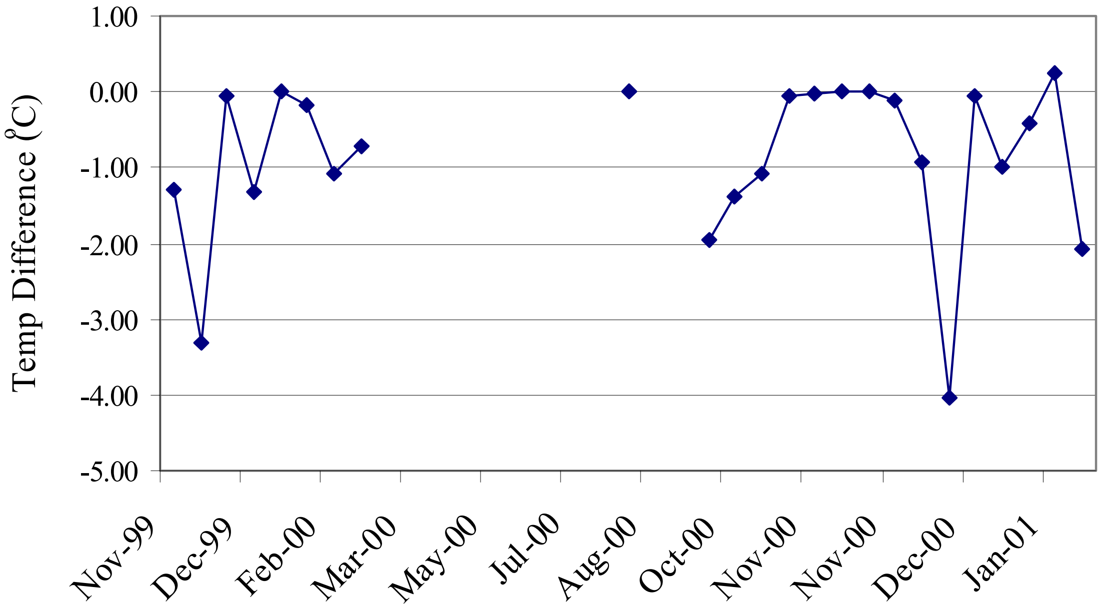


Figure 14. Temperature difference (^{O}C) between surface and 2 m depth, Lake Brewster Site B, 1999 – 2001.

3.2 ELECTRICAL CONDUCTIVITY

3.2.1 Lake Cargelligo

Salts in Lake Cargelligo are primarily derived from river inputs, however limited surface run-off and leaching of salts from the lake bed may also contribute. Additionally salts are concentrated within the storage through evaporation. Seasonal variations in salt loads entering the storage occur depending upon river flow, catchment activity, rainfall and river operations. The affect of inflows upon the water quality of the storage depends upon both the volume of the storage and amount of water entering the system.

Electrical conductivity within Lake Cargelligo storage varied between 358 and 641 µs/cm^2 over the sampling period (Table 7, Appendix 1). Electrical conductivity within the lake was generally higher and had lower variability than the river water (Table 7). Within the lake the greatest fluctuations were found at Site A (refer to Figure 5), which is the monitoring site closest to the inlet channel and therefore mirrors fluctuations found in the river (Figure 15). Site B and C had the least variation, being further away from the inlet channel, both sites were buffered from fluctuating inflow water. The volume of water entering the storage was relatively small compared to the volume in the lake and therefore fluctuations within the main body of the storage are minimal.

Water released from Lake Cargelligo generally had a higher salt content than water entering the system (Figure 16). Electrical conductivity levels in outlet water were higher than inlet water on 87% of sampling occasions by an average of 164 µS/cm^2.

The release of water from Lake Cargelligo storage may be increasing salt concentrations in the Lachlan River (Figures 17). Electrical conductivity was higher at Murrin Bridge (below Lake Cargelligo outlet) than Lake Cargelligo Weir (above Lake Cargelligo outlet) on 76 % of sampling occasions. However, not all electrical conductivity peaks at Murrin Bridge can be related to surface discharges from Lake Cargelligo (Figure 17). These increases may relate to groundwater inflows or other factors not measured in this study.

No apparent increase in electrical conductivity was observed in the Lachlan River between Lake Cargelligo Weir and Lake Cargelligo Outlet (Table 7), indicating that the major contributor to increased salt loads in this section of the Lachlan River comes directly from Lake Cargelligo discharge. Saline stratification of water within Lake Cargelligo did not occur at any of the sites (Figure 18).

Table 7. Summary of electrical conductivity in Lake Cargelligo, 1999 – 2002 (LC = Lake Cargelligo)

	LC Weir	DS LC Weir	LC Site A	LC Site B	LC Site C	Lake Ck	Lachlan R @ Murrin Bridge
N	79	65	78	75	76	79	79
Min	304.6	306.2	358	480	426.3	326	316.0
Max	781.2	817.6	641.2	619.9	598.9	912.0	856.8
Mean	424.5	423.14	466.3	542.9	524.9	550.2	445.7
St Dev	111.0	112.70	61.44	26.8	38.8	75.38	101.27

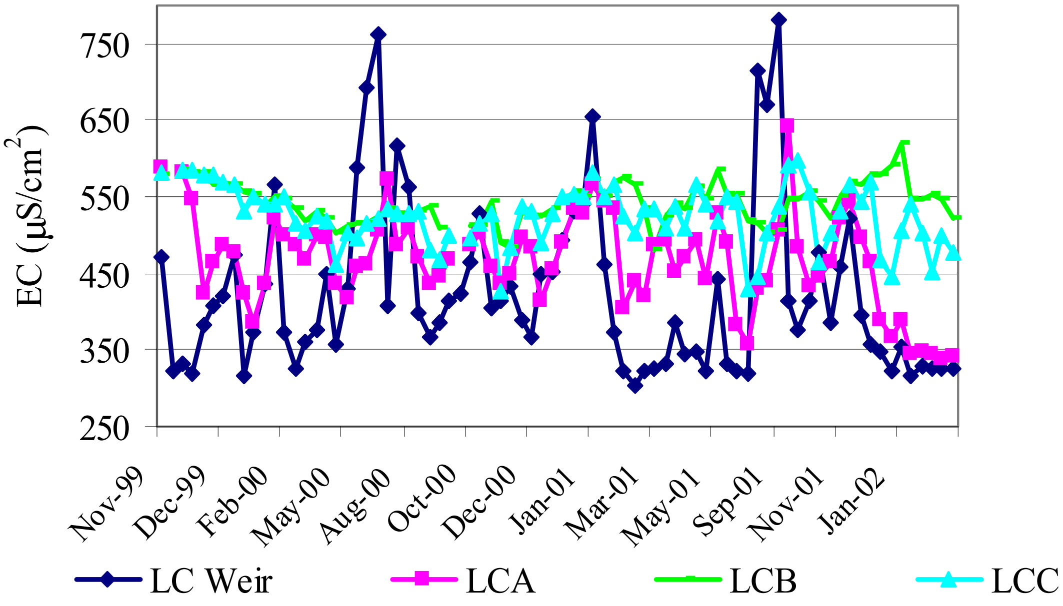


Figure 15. Electrical conductivity at Lake Cargelligo Weir and within Lake Cargelligo, 1999 – 2002.

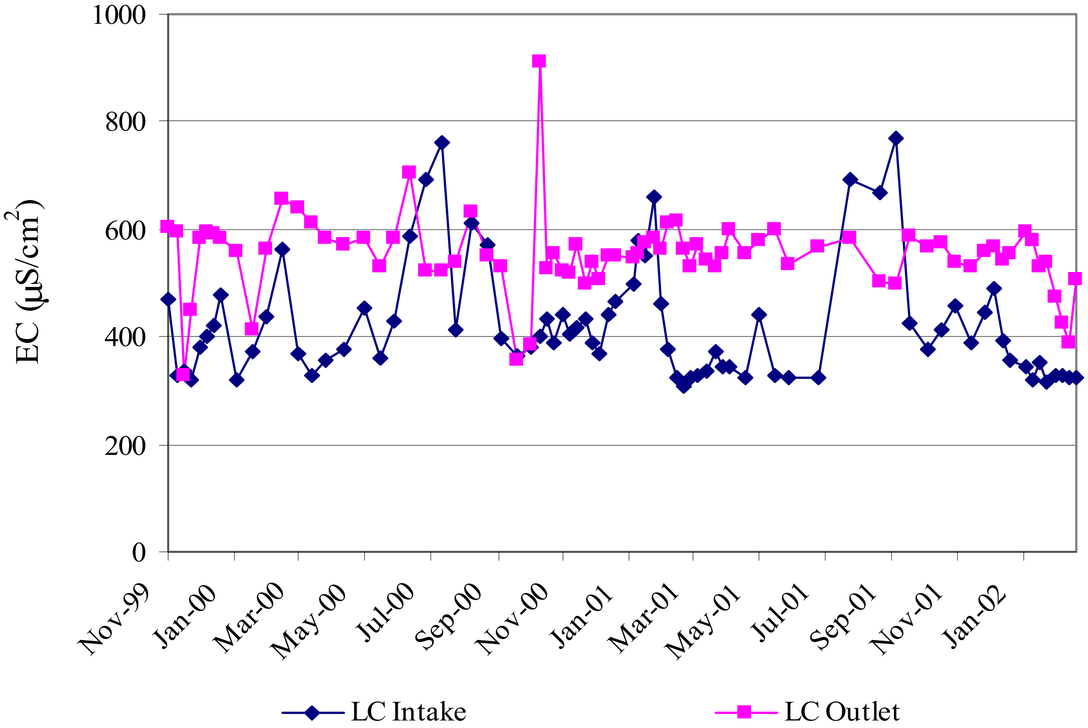


Figure 16. Electrical conductivity at Lake Cargelligo Inlet and Outlet, 1999 – 2002.

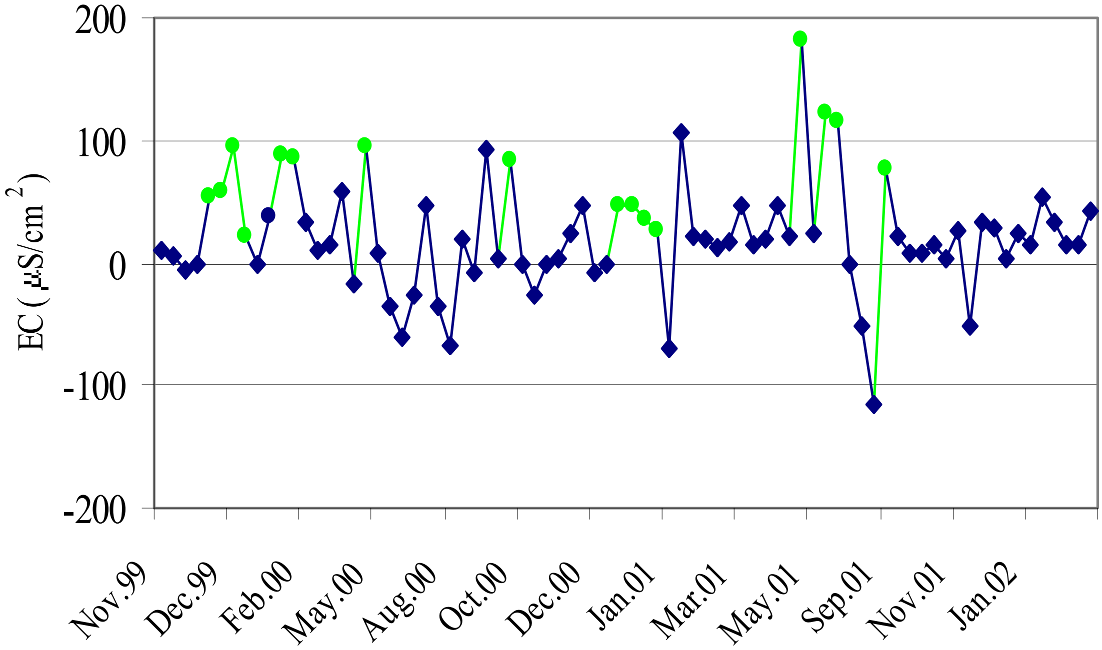
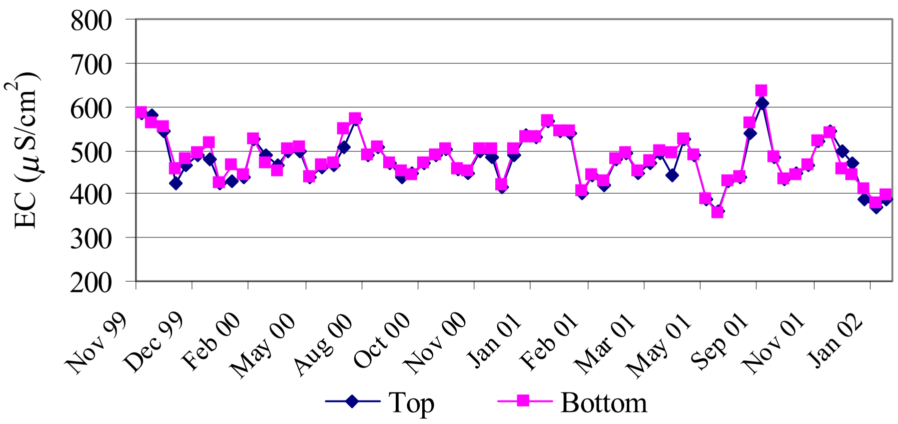


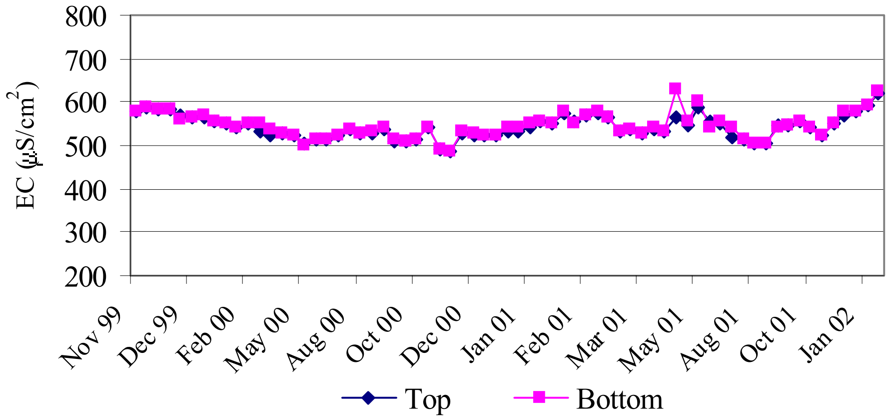
Figure 17 Difference in electrical conductivity in the Lachlan River between the Lake Cargelligo Weir and Murrin Bridge. Green data points indicate when Lake Cargelligo discharge makes up more than 50% of total flow in the Lachlan River at Murrin Bridge. (>0 = EC higher at Murrin Bridge than Lake Cargelligo Weir, <0 = EC lower at Murrin Bridge than Lake Cargelligo Weir).

A water quality study of Lake Cargelligo conducted by the Department of Water Resources (now DSNR) during 1992/93 found that electrical conductivity within the storage ranged from 810 to 920 µS/cm over a one year period (DWR 1992). Compared to 480 to 619 µS/cm (median 545.3 µS/cm) for the current study, electrical conductivity within the storage appears to have dramatically decreased since 1992. 1992 was a large flood year and high electrical conductivity values may be the result of a raised water table and increased catchment runoff.

a) EC Depth Profile - Lake Cargelligo Site A



b) EC Depth Profile - Lake Cargelligo Site B



c) EC Depth Profile - Lake Cargelligo Site C

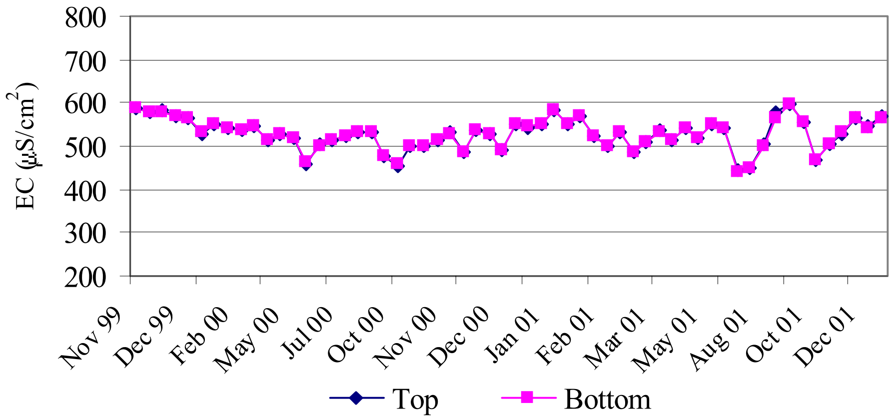


Figure 18. Electrical conductivity profiles (top and bottom), Lake Cargelligo Sites A, B and C, 1999 - 2002

3.2.2 Lake Brewster

Salts in Lake Brewster are primarily derived from river inputs, which are concentrated by evaporation. Lake Brewster's large surface area results in considerable storage losses through evaporation (Table 8). High evaporative losses increase salinity as evaporating water leaves salts behind. When flows into the storage are low, salt concentrations increase and higher salinity water may then be released downstream.

Electrical conductivity was higher in Lake Brewster site B than at Lake Brewster Weir on 73.7 % of sampling occasions (Figure 19, Appendix 1). Water released had a higher conductivity than inlet water on 67.5% of sampling occasions (Table 9, Figure 20).

Willandra Weir, the furthest downstream river site, had higher average electrical conductivity levels than Lake Brewster Weir and the Lachlan River downstream of Lake Brewster Weir over the sampling period (Table 9). This indicates that Lake Brewster discharge was possibly increasing salt concentrations in the Lower Lachlan River.

Flow into Lake Brewster ceased on the 7th January 2001. Outlet flows continued and were increased after a decision to drain the storage and begin de-silting works in the inlet and outlet channels. Electrical conductivity increased dramatically and continued to increase up until late July when sampling from the site was halted due to access difficulties (Figure 21). Isolation of the storage from fresh inputs of river water allowed the salt levels to increase as water evaporated, with no further dilutions coming from the river water. Flow into Lake Brewster inlet channel did not recommence until 2nd December 2001, however water was no longer diverted to the storage, rather it was simply passed along the inlet and out the outlet channel.

Table 8. Lake Brewster monthly evaporation losses (ML), 1994-2001

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Mean	1079.0	1947.2	3415.0	5334.8	7332.9	8975.5	7750.6	4870.5	3891.4	2281.7	1272.2	898.7
Medium	1049.0	1793.9	3353.2	5480.6	7719.2	8655.8	7528.0	5278.3	4119.7	2519.1	1186.6	827.0
Min	103.9	1321.2	1763.8	3111.4	4469.7	1035.4	865.0	686.1	783.7	371.9	198.0	145.3
Max	2326.3	3140.0	5978.3	8798.8	9931.3	16462.9	14546.6	8021.7	5567.3	3102.3	2522.6	1797.5
N	7	7	7	7	7	7	7	6	6	6	6	6

Table 9. Summary of electrical conductivity in Lake Brewster, 1999 – 2002 (LB = Lake Brewster)

	LB Weir	DS LB Weir	LB Site A	LB Site B	LB Site C	LB Dead Storage	Bensons Drop	Lachlan R @ Willandra Weir
N	79	63	59	57	74	26	75	79
Min	284	351	322	321	353.8	458	354.9	320
Max	646.2	649.2	786.9	793.7	767.3	624	776.9	645.6
Mean	443.8	452.6	515.4	529.5	508.9	329.2	515.6	468.8
St Dev	82.65	79.6	92.5	108.5	96.72	48.47	99.5	71.6

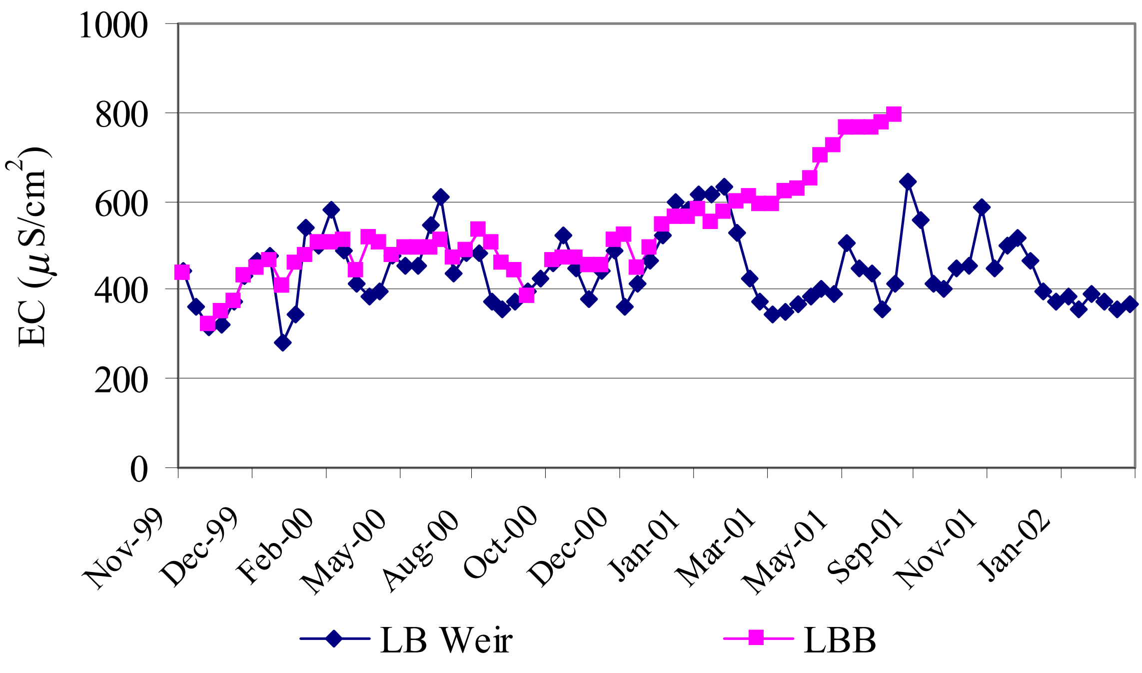


Figure 19. Electrical conductivity at Lake Brewster Weir and Lake Brewster Site B, 1999 – 2002 (sampling ceased in September 2001 at site B due to difficult access)

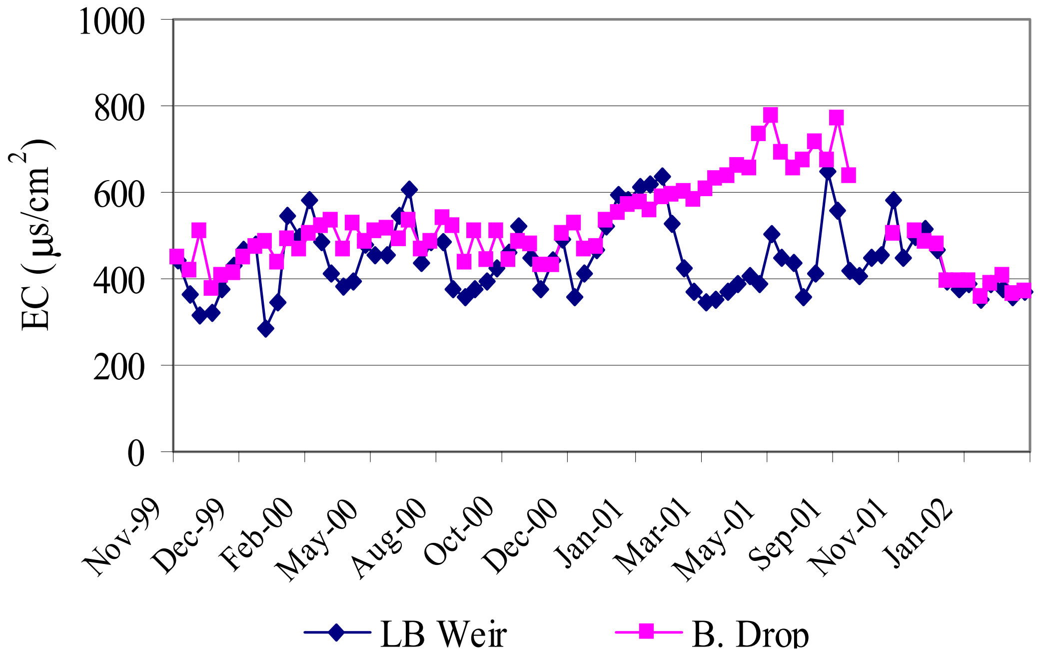


Figure 20. Electrical conductivity at Lake Brewster Weir and Bensons Drop, 1999 – 2002.

The impact of this discharge was evident at sites downstream of Lake Brewster. An increase in electrical conductivity at Bensons Drop Weir, which is at the end of the outlet channel, was apparent. This increase followed the cessation of flow into Lake Brewster on 7th January 2001 and was in-line with increasing salinity of the storage (Figure 21). Towards the end of December 2001, electrical conductivity was dramatically lower at Bensons Drop than it had been in previous months (i.e. September). This was following the completion of de-silting works, when a temporary barrier was constructed to prevent water from entering Lake Brewster Storage, instead water flowed along a modified inlet channel and outlet channel, effectively bypassing the storage. At these times the inlet and outlet channels acted as little more than an arm of the river and, as a result, electrical conductivity values between Lake Brewster Weir and Bensons Drop are similar. The modified channel bypassing the storage remained in place until completion of the project.

The impact of high salinity release from Lake Brewster upon water quality of the Lower Lachlan River following the 7th January 2001 was relative to release volume (Figure 21). As the lake is drawn down, it became difficult to release large volumes of water through the outlet regulator and so a marked decrease in the volume of water released from the storage was apparent. To compensate the low volume release, larger volumes of water were released through the conduit and over Lake Brewster Weir. The higher saline but low volume Lake Brewster water met the moderately saline high volume water from the conduit just below Bensons Drop with the result of highly saline water being diluted by the water released through the conduit (Figure 22). Ultimately low volumes of highly saline water has limited impact upon the lower reaches of the river provided sufficient volumes of non-Brewster water are released to buffer it.

The combined flow of Lake Brewster outlet, over weir and conduit flow makes up the total flow to the lower reaches of the Lachlan River. Increasing the flow of river water can therefore be used to dilute high saline releases from Lake Brewster.

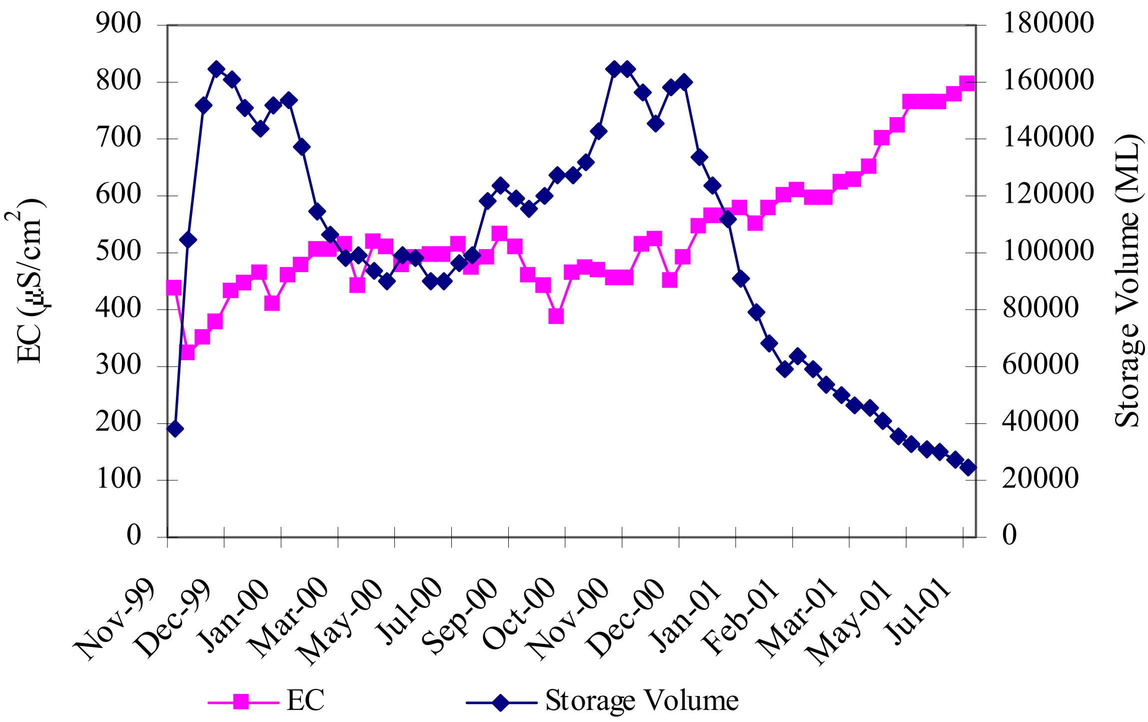


Figure 21. Lake Brewster electrical conductivity vs lake height, 1999 – 2001.

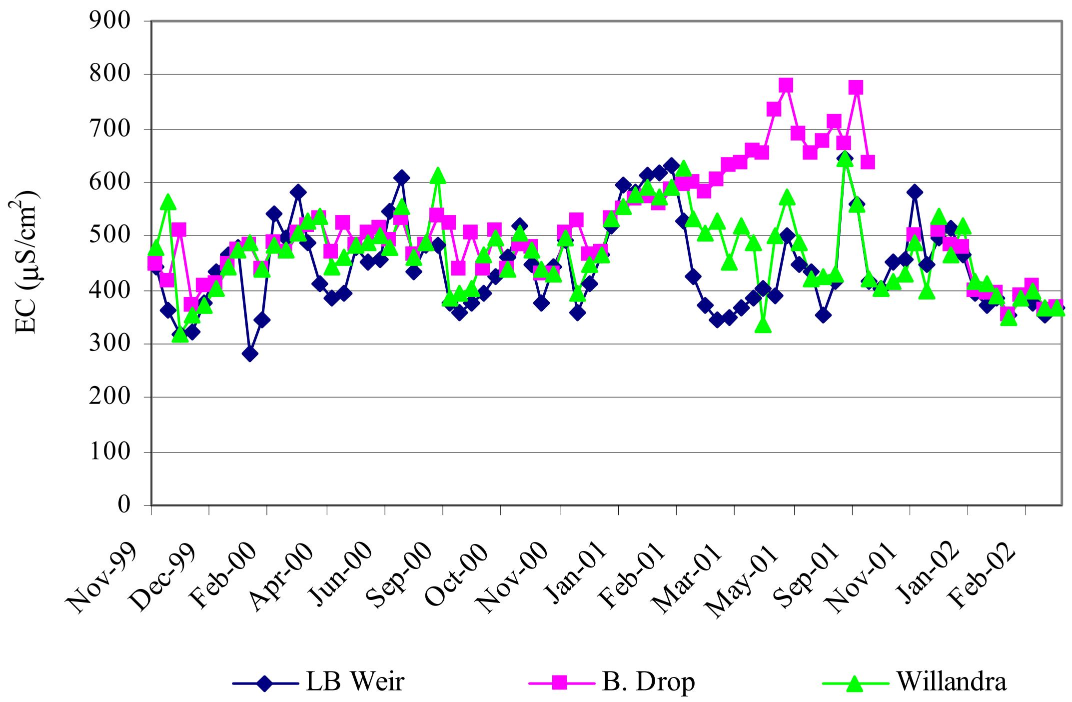


Figure 22. Electrical conductivity at Lake Brewster Weir, Willandra Weir and Bensons Drop, 1999 – 2002.

3.2.3 Impact of salinity on biota of the storages and lower reaches of the river

Salinity within Lake Cargelligo was generally higher than Lake Brewster. Electrical conductivity was higher in both storages than the river and the electrical conductivity of outlet water from both lakes was higher than inlet water. The impact of saline releases upon lower reaches of the river depends upon the volume and electrical conductivity of the receiving river water.

Impacts of salinity on biota will vary depending on the sensitivity to changes in electrical conductivity. Aquatic organisms can be classified as stenohaline (able to adapt to a narrow range of salinities) or euryhaline (able to adapt to a wide salinity range) (Hart *et al.* 1991). Plants are also divided into two groups, haliphotic plants are salt tolerant, non-haliphotic are adversely affected by increasing salinities.

Increasing salt concentrations in rivers and lakes are known to affect ecological processes. Changes in salinity affects freshwater biota directly by a range of toxic effects through physiological changes (particularly osmoregulation), resulting in a change in diversity by the loss (or gain) of species. Indirect changes in species diversity can occur as a consequence of direct toxic effects modifying community structure and function by the removal (or addition) of taxa that provide refuge and/or food and reducing reproductive ability (Nielsen 1999).

Adverse biological effects are expected in Australian aquatic ecosystems if salinity increases to around 1500µS/cm (1000 mg/L) (Hart *et al* 1991). Above this threshold many macrophytes and invertebrate taxa are known to have reduced abundance and diversity. A preliminary investigation measuring the impact of increasing salinity on the composition of wetland communities found a significant loss of macrophyte taxa at salinities above 300 mg/L (Neilsen and Brock 2002). However, for the majority of aquatic taxa very little research has investigated the effects of salinity at concentrations below 1500 µS/cm on recruitment, reproduction or survival of early life stages (Nielsen 1999).

Lake Cargelligo and Lake Brewster generally ranged between 400-500 µS/cm, neither storage exceeded the recommended guideline of 1500 µS/cm during the study period (ANZECC and ARMCANZ 2000). However, it should not be considered that water quality was "healthy" and no adverse effects on the biota or ecosystems were occurring.

3.3 TURBIDITY AND SEDIMENTS

Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level (Scheffer 1998). Suspended or colloidal matter such as clay, silt, fine organic and inorganic matter, algae and other microscopic organisms cause turbidity in water (Weyhenmeyer 1998). Suspended material in Lake Cargelligo and Lake Brewster originates from allochthonous (transport of material into the lake) and autochthonous (production of material within the lake) sources. Transport of material into the lakes comes directly from the Lachlan River and in-lake production of material originates from processes such as algal growth and sediment resuspension.

3.3.1 Lake Cargelligo

The recreational and town water supply commitment of Lake Cargelligo requires the storage to be kept at around 70% of full supply level. The rapid draw-down and refilling of Lake Brewster does not occur in Lake Cargelligo and, because water is kept at depth, wind driven sediment resuspension does not have a large impact upon turbidity. Mean turbidity levels were less than 50 NTU in the Lake Cargelligo storage (Table 10, Appendix 1). However turbidity was higher downstream of Sheet of Water, a shallow water body on the inlet channel (refer Figure 2), and in Lake Creek, the Lake Cargelligo outlet (LCO) channel (Table 10, Figure 23).

Increases in turbidity downstream of Sheet of Water were probably the result of wind driven sediment resuspension (Table 10, Figure 23). The shallow nature of the Sheet of Water would allow wind driven waves to pick up sediment from the bottom of the storage. Turbidity decreased downstream of Curlew Water (refer Figure 2) which is a deeper water body than Sheet of Water and is better protected from wind-driven sediment resuspension (Table 10, Figure 23).

Turbidity in Lake Cargelligo remained at a lower levels than those found in Sheet of Water and Curlew Water but increased in Lake Creek which may be the result of higher water velocities lifting sediments of the outlet channel (Table 10, Figure 23). The result of higher turbidity in faster flowing water was an increase in mean turbidity at Murrin Bridge, the site immediately downstream of Lake Cargelligo when compared to upstream river sites (Table 10, Figure 23). The size of the increase depends upon the volume of water released from Lake Cargelligo.

Table 10. Turbidity of Lake Cargelligo sites, 1999 – 2002. (LC = Lake Cargelligo)

	N	Min	Max	Mean	Std. Dev.
LC Weir	79	15.7	133.0	44.07	20.90
LC Intake	79	11.9	146.0	44.82	21.17
DS Sheet of Water	79	17	200.0	61.16	33.16
DS Curlew Water	79	12.0	104.0	40.46	17.87
LC Site A	78	16.2	85.5	44.13	15.80
LC Site B	75	5.1	81.9	30.41	16.18
LC Site C	76	9.3	170.7	46.19	25.02
Lake Creek	79	17.6	170.0	70.14	26.48
Lachlan R @ Murrin Bridge	79	24.6	165.0	54.51	21.88
Lachlan R d/s LC Weir	65	14.2	133.0	44.69	19.08

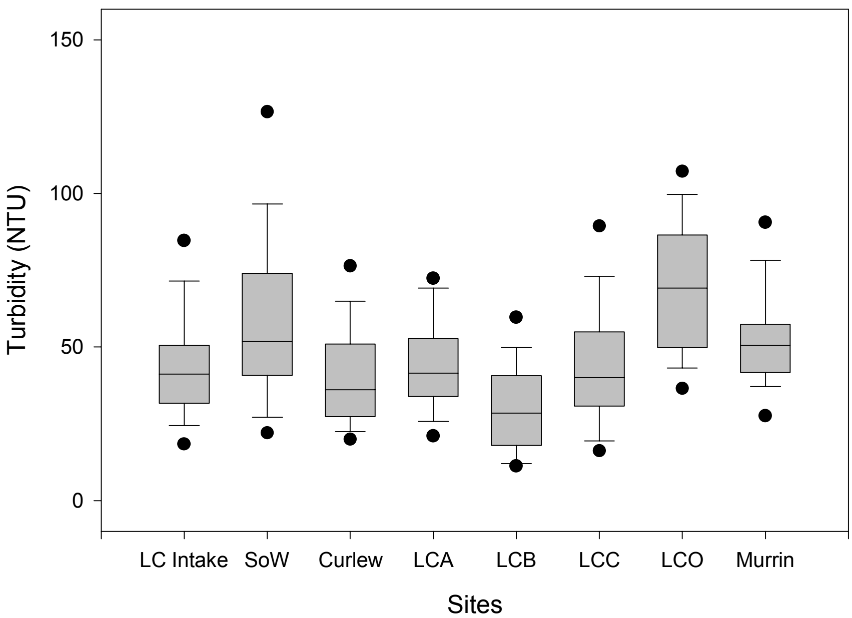


Figure 23. Turbidity from Lake Cargelligo Weir to the Lachlan R at Murrin Bridge, 1999 - 2002

Suspended solid concentrations are closely linked to turbidity. Suspended solid results reflect similar patterns to turbidity with an increase downstream of Sheet of Water and in Lake Creek, which ultimately increased suspended solid concentrations in the Lachlan River at Murrin Bridge (Table 11, Figure 24).

Table 11. Suspended solid concentrations of Lake Cargelligo sites, 1999 – 2002. (LC = Lake Cargelligo)

	N	Min	Max	Mean	Std. Dev.
LC Weir	72	2.5	178.0	35.26	29.57
LC Intake	69	7.0	151.0	33.78	21.98
DS Sheet of Water	69	9.0	100.0	38.23	19.56
DS Curlew Water	75	2.5	62.0	20.57	11.82
LC Site A	72	2.5	65.0	28.81	12.95
LC Site B	68	2.5	52.0	17.37	11.33
LC Site C	68	8.0	85.0	34.19	18.35
Lake Creek	72	2.5	370.0	61.52	46.87
Lachlan R @ Murrin Bridge	63	5.0	230.0	47.44	32.63
Lachlan R d/s LC Weir	64	10.0	154.0	37.09	27.34

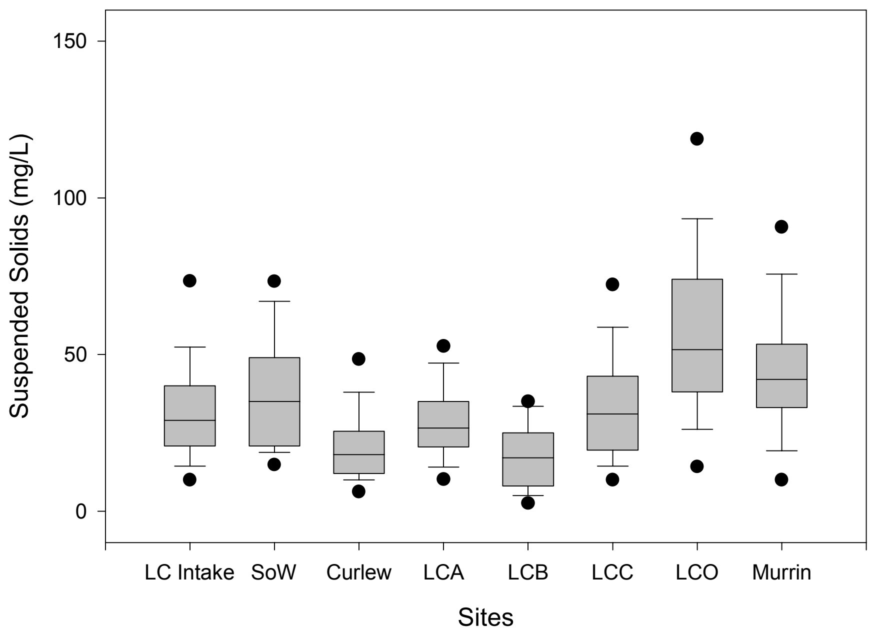


Figure 24. Suspended solid concentrations from Lake Cargelligo Weir to the Lachlan R at Murrin Bridge, 1999 - 2002

Suspended solids were also measured using automatic samplers on the inlet and outlet channels of Lake Cargelligo. Automatic samplers were used to increase the frequency of sampling suspended solids entering and leaving the lakes. (Figure 25). Generally, suspended solid loads leaving Lake Cargelligo were greater than those entering (Figure 25). This is most obvious in February 2000 when outflow loads were considerably higher than inflow loads. This appears to be the result of 3 days of reasonably high outflows from the lake (average of about 450 ML/D) and high suspended loads concentrations (around 60 mg/L).

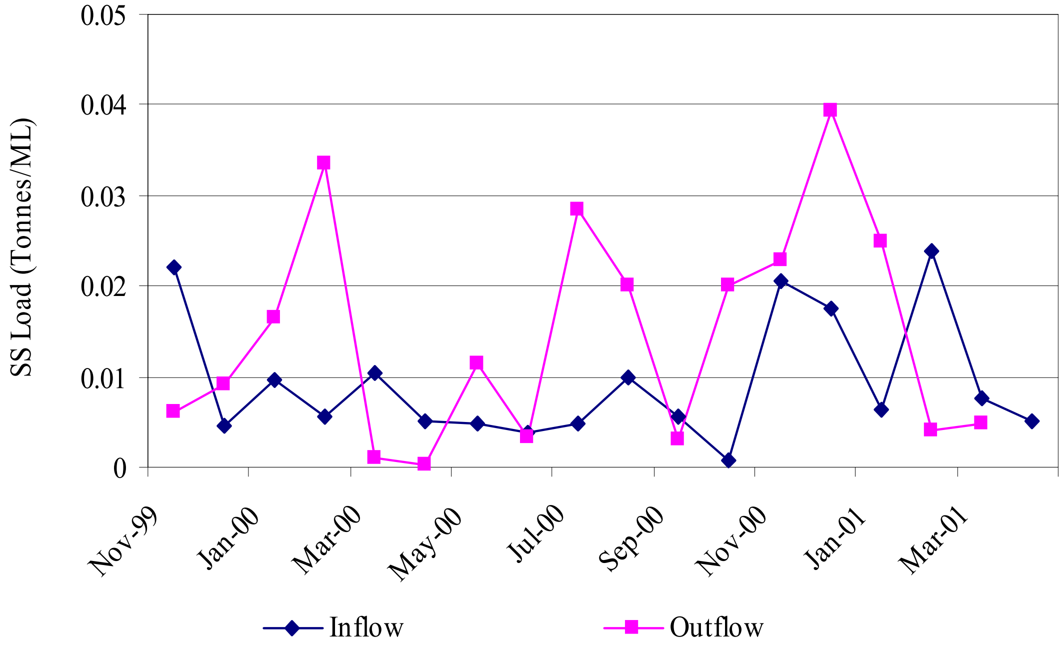


Figure 25. Lake Cargelligo inlet and outlet average monthly suspended solids loads per megalitre, 1999 – 2001.

3.3.2 Lake Brewster

Increasing turbidity and suspended sediment loads in Lake Brewster are a major concern for the management of the Lower Lachlan River. Turbidity within Lake Brewster was high and the release of water from the storage into the Lachlan River may have caused problems for aquatic biota and downstream users (Table 12). The release of water high in suspended sediments is known to impact upon aquatic systems by:

- reducing light penetration and inhibiting plant growth (Moss 1998);
- smothering macroinvertebrate habitats and fish spawning areas;
- increasing sediment loads which can aggrade the river channel;
- deterioration of irrigation equipment; and
- reducing the aesthetic value of the river.

Turbidity of river water increased following its introduction into the Lake Brewster Storage (Table 12, Figure 26) and release of this water from Lake Brewster increased the turbidity of the lower reaches of the river (Table 12, Figure 26).

Mean and median turbidity was highest at Lake Brewster Outlet, this site also had the highest variation (Table 12, Figure 26, Appendix 1). Mean turbidity was lowest at Lachlan River downstream of Lake Brewster Weir, followed by Lake Brewster Weir pool (Table 12). The Lachlan River downstream of Brewster Weir (before Lake Brewster outflow) generally receives low flows as water is passed from the weir through Lake Brewster. Suspended solids and turbidity would also settle out in Lake Brewster Weir pool, further increasing water clarity at this site (Table 12, Figure 26). The highest maximum turbidity was recorded at Lake Brewster Outlet and Lake Brewster site C (Table 12). Lake Brewster site C also had the lowest recorded turbidity, which indicates the large variation at this site.

Table 12. Turbidity of Lake Brewster Sites, 1999 – 2002. (LB = Lake Brewster)

	N	Min	Max	Mean	Std. Dev.
LB Weir	78	7.22	136.00	39.00	20.31
LB Intake	78	17.20	124.00	43.65	19.80
LB Intake @ Lake	78	16.70	197.20	66.30	35.60
LB Site A	57	26.70	191.00	84.10	39.53
LB Site B	73	18.00	210.00	85.29	45.24
LB Site C	27	3.29	274.00	85.66	56.15
LB Dead Storage	55	19.60	154.50	68.58	34.17
LB Outlet	73	20.50	378.00	97.37	67.05
Bensons Drop	77	7.08	254.60	94.17	51.68
Willandra Weir	77	24.50	115.00	51.46	17.85
Lachlan R d/s LB Weir	62	11.20	101.90	34.58	15.81

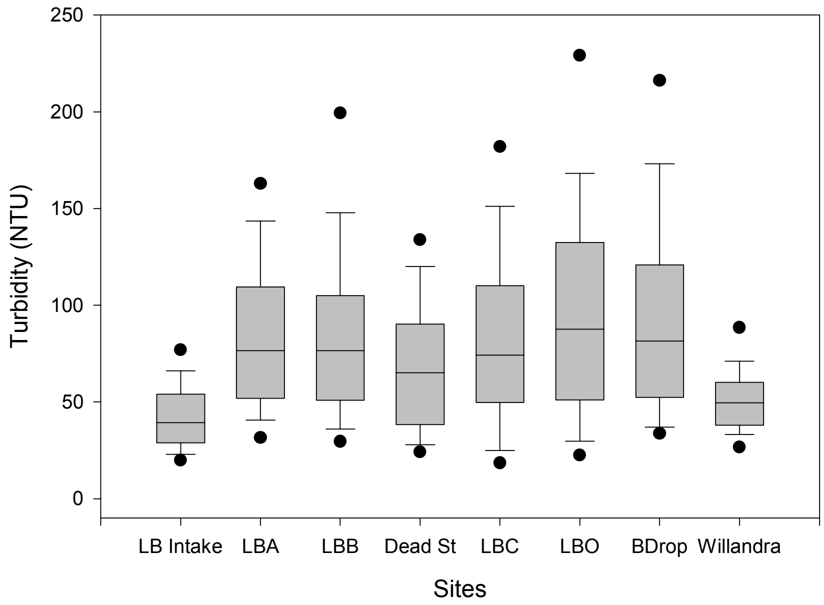


Figure 26. Turbidity of monitoring sites above, below and within Lake Brewster, 1999 - 2002.

Turbidity in Lake Brewster Storage was higher than turbidity in Lake Brewster Weir on 81 % of sampling occasions (Figure 27). The greatest differences in turbidity between Lake Brewster storage and Lake Brewster Weir were observed between March and September 2000 and 2001 (Figure 28). It was during these autumn and winter months that the storage dropped below 100 000 ML (Figure 21) and its is likely wave action may have had a greater impact on lake sediments.

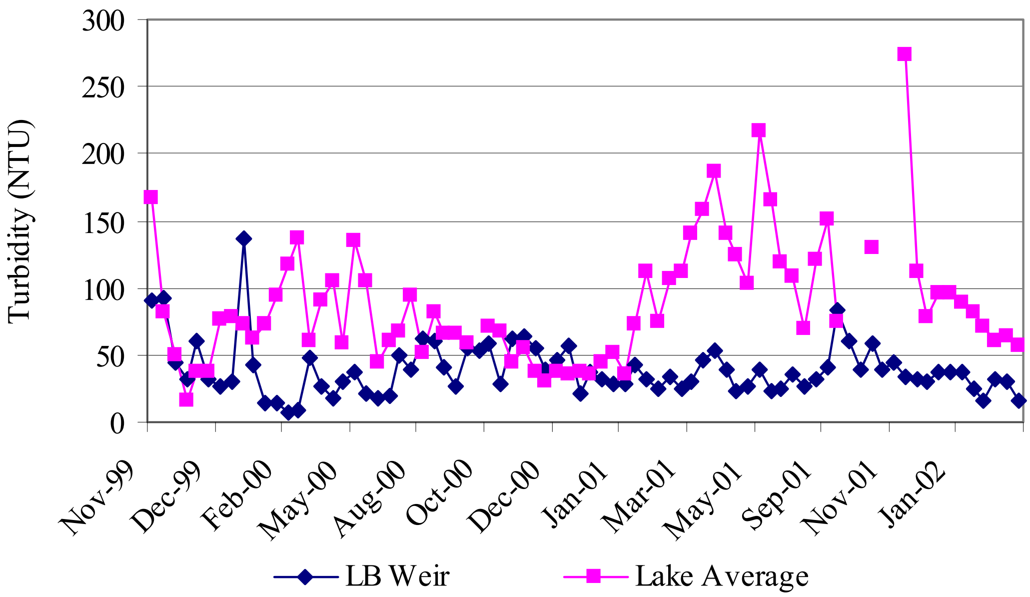


Figure 27. Turbidity of Lake Brewster Weir and Lake Brewster Storage (average of Lake Brewster sites A, B and C), 1999 - 2002

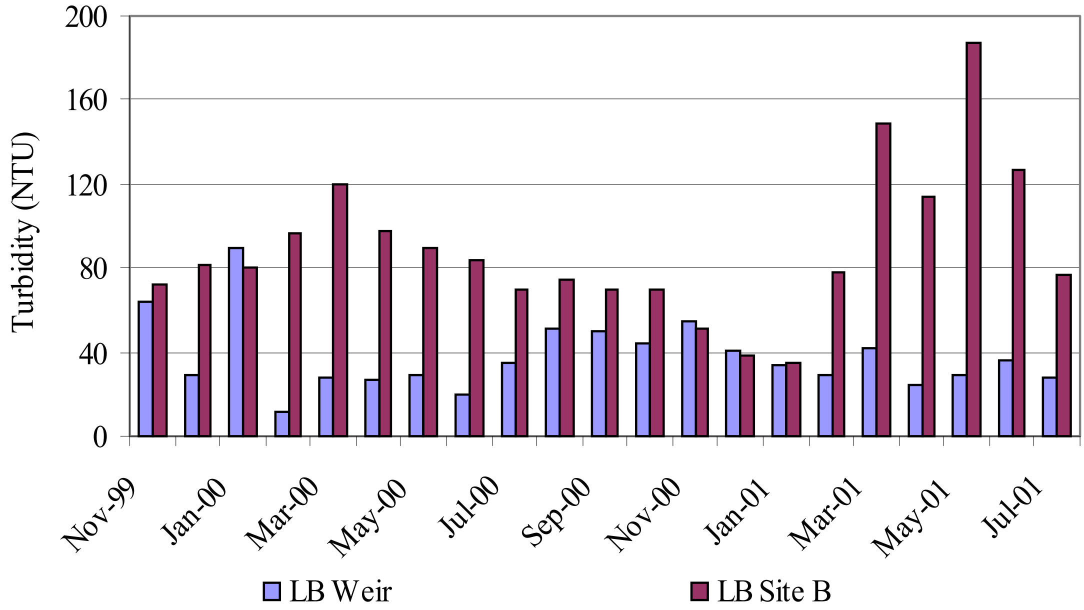


Figure 28. Average monthly turbidity at Lake Brewster Weir and Lake Brewster Site B, 1999 - 2001.

Correlation analysis was undertaken to look at the relationship between turbidity at Lake Brewster outlet and Willandra Weir. The following data were excluded, as they were not considered to accurately reflect normal operation of the storage:

- data corresponding to when Lake Brewster volume was less than 50 000 ML - release of water when the storage is below this level is not considered to be sufficient to impact upon the river and is outside the volume the storage is usually kept at, and
- data corresponding to water released over Lake Brewster Weir, including environmental flows; during this time the operation of Lake Brewster Weir does not reflect general operating procedures.

When excluding the data within the parameters mentioned above a strong positive relationship was found to exist between the turbidity at Lake Brewster Outlet and Willandra Weir. This indicates that turbidity at Willandra Weir is strongly influenced by releases from Lake Brewster (Figure 29).

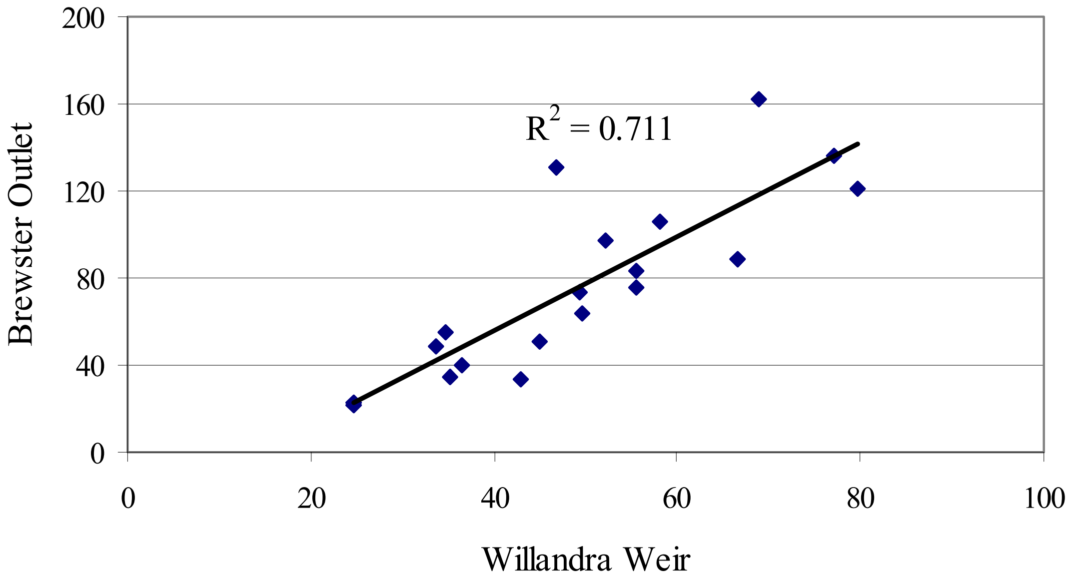


Figure 29. Relationship between turbidity (NTU) at Willandra Weir and Lake Brewster outlet, 1999 – 2002

Mean suspended solid concentrations were higher in Lake Brewster and the outlet compared to those found in Lake Brewster Weir and immediately downstream of Lake Brewster Weir (Table 13, Appendix 1). Lake Brewster site C, Lake Brewster Outlet and Bensons Drop also had the highest variation (Table 13, Figure 30). As was the case with turbidity, the highest maximum turbidity was recorded at Lake Brewster Outlet and Lake Brewster Site C (Table 13).

Table 13. Suspended solid concentrations of Lake Brewster Sites, 1999 – 2002. (LB = Lake Brewster)

	N	Min	Max	Mean	Std. Dev.
LB Weir	69	2.5	140.0	26.92	23.28
LB Intake	71	2.5	77.0	28.99	16.07
LB Intake @ Lake	73	2.5	142.0	49.42	30.63
LB Site A	58	2.5	170.0	53.04	39.40
LB Site B	56	2.5	200.0	49.82	40.77
LB Site C	66	2.5	310.0	70.95	61.13
LB Dead Storage	26	2.5	73.0	31.48	21.14
LB Outlet	50	7.0	470.0	89.18	72.82
Bensons Drop	67	5.0	210.0	78.82	48.81
Willandra Weir	70	2.5	80.0	37.59	16.06
Lachlan R d/s LB Weir	61	7.0	78.0	26.51	13.63

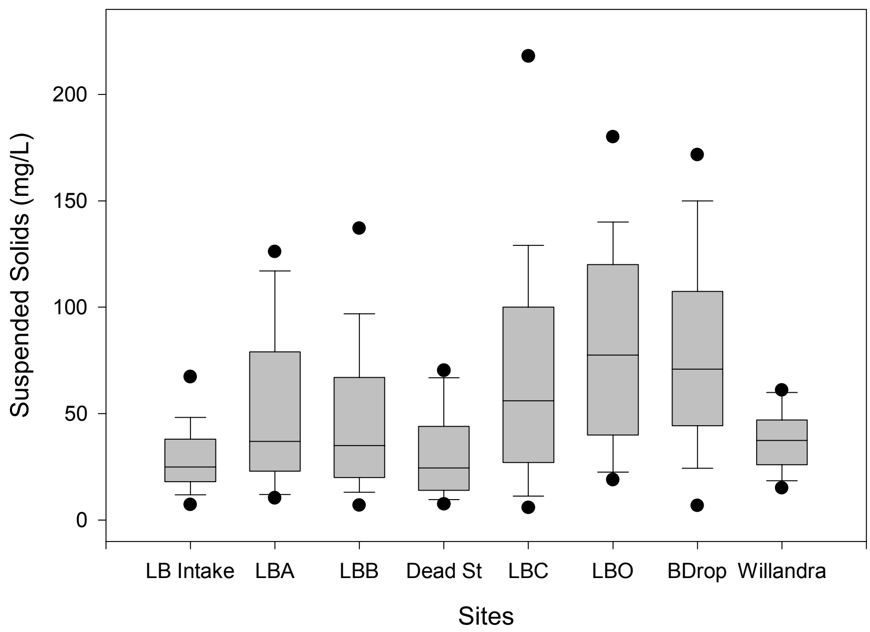


Figure 30. Suspended solid concentrations from Lake Brewster Weir to the Lachlan River at Willandra Weir, 1999 - 2002

Figure 31 shows the average total suspended solid load for each month released at Lake Brewster recorded at Bensons Drop Weir with average monthly flow. Sediment release downstream increased following the re-introduction of water into the outlet channel in November 1999 and December 2001.

Suspended solid loads entering Lake Brewster were generally lower than those leaving the lake (Figure 32). The highest suspended solid loads occurred during the highest outflows from Lake Brewster (Figure 32). As discharge increases from the lake, flow velocities increase along the outlet channel, with the result of increased resuspension of sediment. Obviously, increased discharge also means increased load, therefore discharge volume may be the major factor determining load, rather than suspended solid concentration.

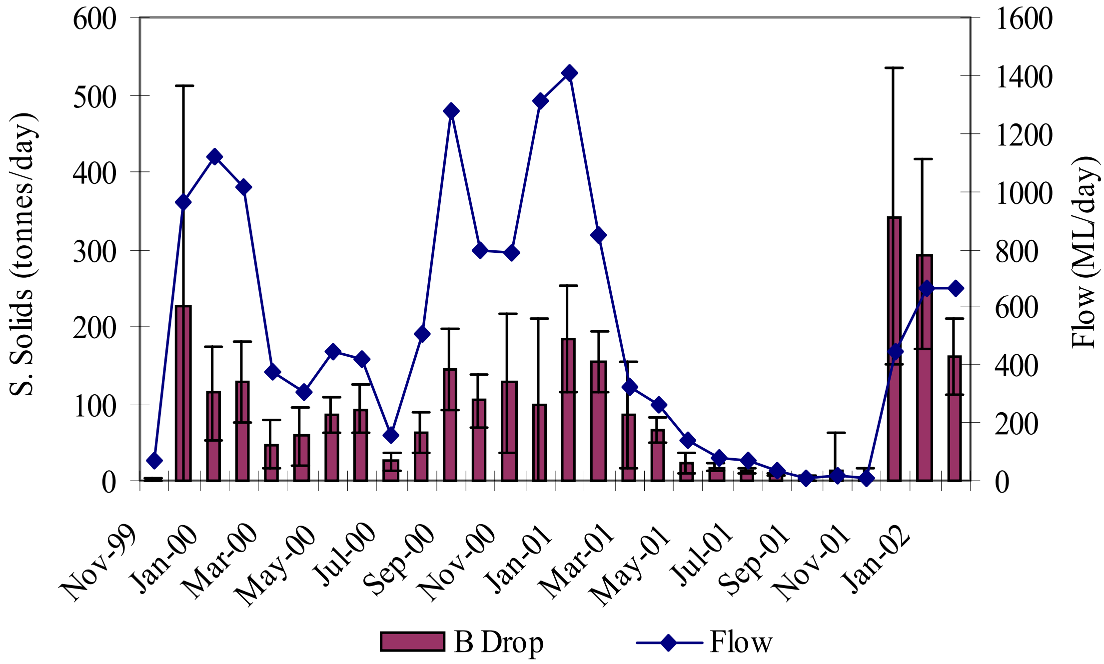


Figure 31. Average daily suspended solid load (tonne/day) at Bensons Drop Weir, 1999 - 2002

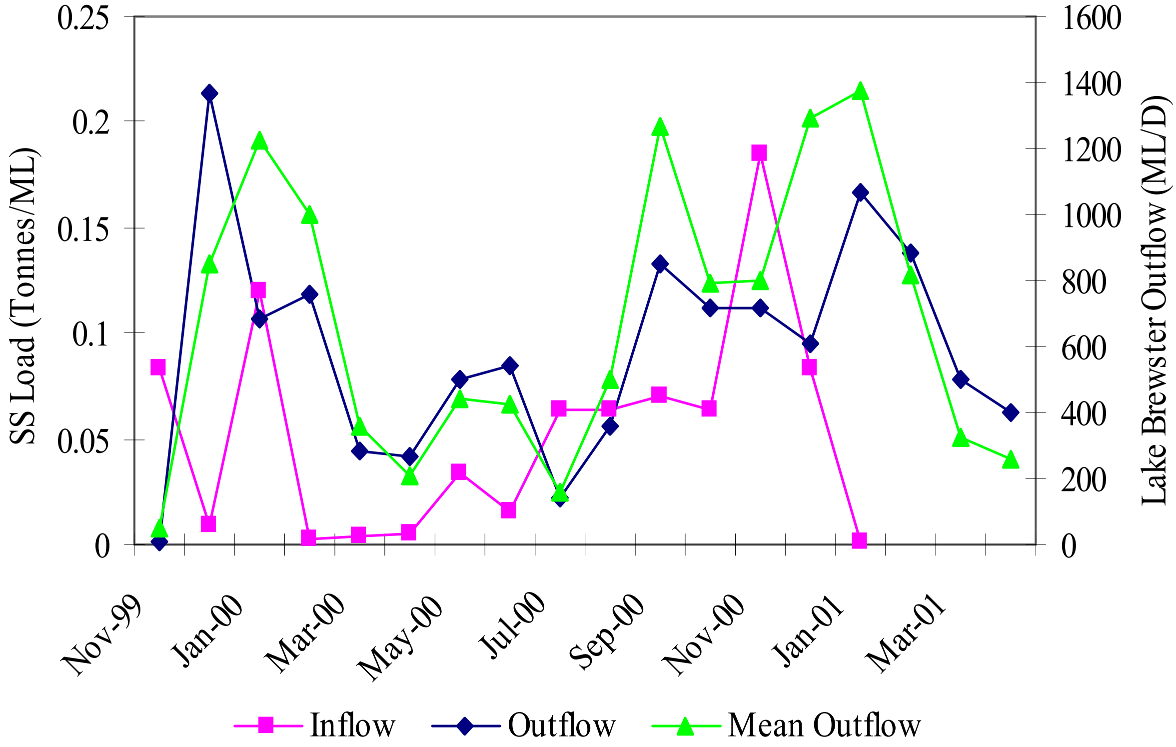


Figure 32. Lake Brewster inlet and outlet average monthly suspended solid loads and outflows, 1999-2001.

3.3.3 Lake Brewster Sediment Study

The resuspension of sediments by wind induced wave action is thought to be the major contributor of suspended material in Lake Brewster. A separate study was undertaken to determine the source of suspended sediments in Lake Brewster. The study examined the lakebed sediment properties of Lake Brewster to help identify target areas for rehabilitation and management. The sites and methods for this study are outlined in Section 2.

The Lake Brewster lakebed was composed of very fine sediments. Fine clays (<0.002 mm) contributed to over 50% of total sediments in 9 out of the 15 sites sampled (max 70 % at Site 2A) (Table 14, Figure 33). Fine clays are the most susceptible to resuspension and are likely contributors of most of the suspended material in Lake Brewster.

Sediments in the northern section of the lake (section 1samples) had a coarser composition, with a much higher concentration of fine to medium sands (0.063 - 2.0mm) (Table 14, Figure 33). The coarser sediments may occur naturally, have been deposited by high river flows or have been transported in with various earth works conducted on the storage wall. The coarser sediments are less susceptible to various resuspension processes and this part of the storage may be a target area for the re-establishment of aquatic plants.

Table 14. Particle size analysis of Lake Brewster sediments (% composition)

	Particle Size Analysis					
Sample No.	**<0.002 mm** (clay)	**0.002-0.02mm** (clay/silt)	**0.02-0.063mm** (silt)	**0.063-0.2mm** (fine - very fine sand)	**0.2-2.0mm** (medium - coarse sand)	**>2.0mm** (gravel)
1A	42	6	14	30	8	0
1B	16	1	13	45	25	<1
1C	42	6	13	31	8	<1
1D	12	2	14	41	31	<1
1E	46	10	17	23	4	0
2A	70	7	7	13	3	<1
2B	62	8	11	14	5	0
2C	59	21	9	11	<1	0
2D	55	5	9	24	7	0
2E	58	20	10	11	1	0
3A	62	5	11	14	8	<1
3B	44	17	11	20	8	0
3C	60	13	11	13	3	0
3D	60	13	11	14	2	0
3E	58	16	10	12	4	0

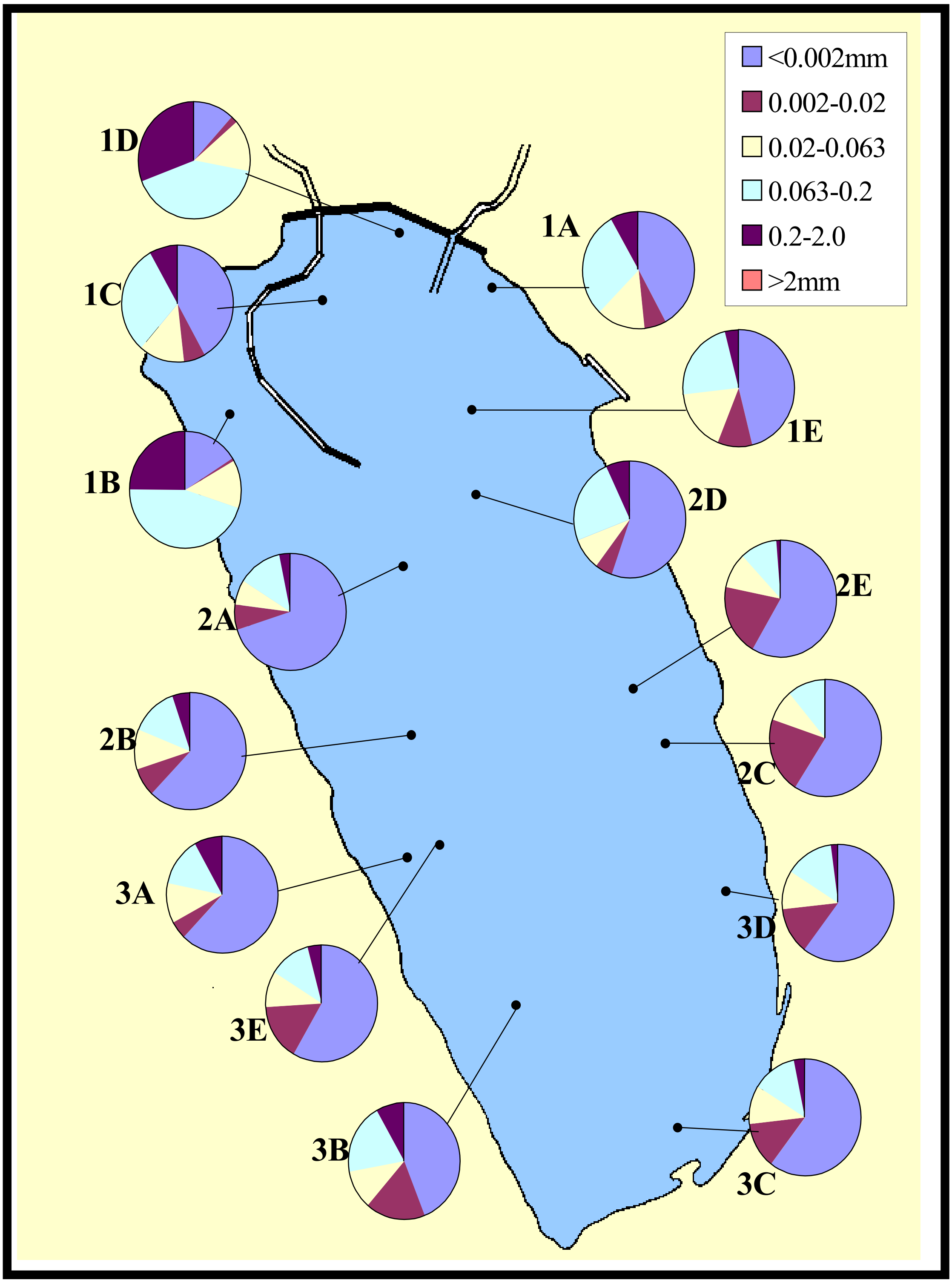


Figure 33. Lake Brewster substrate sediment particle size

■ 3.3.3.2 Wind Action

The predominant wind direction was from the south-east, running the length of the storage at an average velocity of 2.97 m/s (Table 15). Strong winds generate shallow water waves and resuspension occurs when these waves enter water shallower than one-half of their wavelength (Bloesch 1995). The fine (predominantly <0.002mm), colloidal (settling rate of <0.1 mL/L per 48 hours, see Section 2 for methods) sediments of the lakebed were lifted and reintroduced to the water column. These findings suggest wind induced wave action was a major cause of sediment resuspension in Lake Brewster and was a key contributor to the high turbidity of the storage.

Table 15. Wind direction and velocity (m/s) at Lake Brewster, 2000.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Predominant Wind Direction	SE-S	SE-S	SE-S	SE-S	SE-S	NW-N	SE-S	NW-N	SE-S	SE-S	E-SE	SE-S
Max Velocity	9.97	9.56	6.12	8.93	6.46	6.06	8.80	9.49	8.34	10.7	8.75	11.5
Min Velocity	0.32	0.29	0.34	0.29	0.28	0.28	0.28	0.28	0.34	0.28	0.28	0.28
Average Velocity	3.34	2.95	2.91	2.93	2.28	1.17	2.20	2.05	3.11	4.25	3.30	4.46

Increasing the depth of the storage can reduce the impact of wave action upon lakebed sediments. Figure 34 shows that as the storage volume in Lake Brewster increases, turbidity decreases. The correlation that exists between turbidity and water depth at Lake Brewster site B provides supporting evidence that as storage level decreases, turbidity increases (Figure 35). The relationship between depth and turbidity was even stronger at Lake Brewster Outlet (Figure 36).

When the storage level is high, only the shallow shorelines are exposed to wave action (Figure 37). As the water level is drawn down a larger area (and at times the whole wetted area of the lakebed) is exposed to wave action, increasing sediment resuspension and therefore turbidity. Maintaining the storage at a height above which the shallow waves impact upon the lakebed may reduce sediment resuspension but it will also reduce light penetration, restricting plant growth which is often the recommended means to reduce turbidity in large, shallow waterbodies.

The depth to which light can penetrate into a waterbody is limited by the concentration of suspended particles in the water. High concentrations of suspended particles limit light penetration by absorbing and scattering light. Light penetration in Lake Brewster storage decreased as turbidity increased (Figure 38). Figure 38 demonstrates a close relationship between increasing turbidity and decreasing light penetration as represented by euphotic depth. Reduced light penetration limits photosynthesis by plants and can significantly affect lake metabolism.

Resuspended sediments also act as an internal source of nutrients (Luettich R. Jr *et al* 1990). The concentration of total nitrogen and total phosphorus in Lake Brewster increased with the concentration of suspended sediments (see Section 3.4). Nutrients accumulate in lakebed sediments driven by the decomposition of dead organic material (Scheffer 1998). Resuspension of sediments either by wind driven wave action or bioturbation, reintroduce nutrients to the water column and can instigate algal blooms (see Section 3.4).

Three factors have been identified that exacerbate the wind driven resuspension processes that occur in Lake Brewster and all are interrelated, they include:

1. <u>Loss of aquatic vegetation</u> - Aquatic vegetation provides protection from wave action by binding the sediments with root matings, physically obstructing wave velocity and aiding in the sedimentation and flocculation of suspended solids. Accordingly, the re-establishment of macrophytes is often recommended as a means to reverse increases in turbidity. Historical evidence indicates that aquatic plants were once abundant in Lake Brewster storage, in particular Cumungi (*Typha spp*), Ribbonweed (*Vallisneria gigantea*) and Milfoil (*Myriophyllum)*. The loss of aquatic vegetation is often attributed to the introduction of European Carp (*Cypinus carpio*) but is also likely to be the result of an altered flow regime and the rapid draw down and refilling of the storage. Grazing and lake-bed cropping may also adversely affect the growth and reproduction of aquatic vegetation and its associated seedbank. The near complete absence of permanent aquatic vegetation within Lake Brewster storage means sediments are not bound, easily resuspended and the resulting high turbidity reduces light penetration, making re-establishment and recruitment of macrophytes difficult.
2. <u>European Carp</u> - The loss of aquatic vegetation and reduced water quality is often attributed to the introduction of the exotic European Carp (*Cypinus carpio*). European Carp entered the Lachlan River during the floods of the 1970's and have since dominated most sections of the river, in particular its water storages. In search of food, Carp 'well' into the sediment (up to 12 cm) (Alikunhi 1966) disturbing and often uprooting aquatic plants and simultaneously resuspending sediments and increasing turbidity. Indirect bioresuspension occurs when the microtopography of the lakebed is altered, which can increase resuspension rates (Davis 1993).
3. <u>Altered flow regime</u> - Flow patterns of the Lachlan River have been altered alongside agricultural development in the catchment. Summer flows are generally greater while winter flows less. Aquatic flora and fauna that have evolved with natural flow patterns, suffer from this 'reverse seasonality' of flows with recruitment and survival rates reduced and through having to compete with introduced species that may better adapted to the altered flow conditions.

The release of water from Lake Brewster increased sediment loads transported downstream. There appeared to be a close relationship between turbidity at Lake Brewster Outlet and Willandra Weir. High turbidity and suspended solids loads can severely impact upon ecological processes of the river in the following ways:

- light penetration is restricted reducing both algal and macrophyte growth;
- increased nutrient concentration;
- conditions for submerged macrophytes and biota deteriorate due to siltation;
- reduced aesthetics;
- may render water unpalatable and expensive to treat;
- may harm and reduce the working life of farm and irrigation equipment.

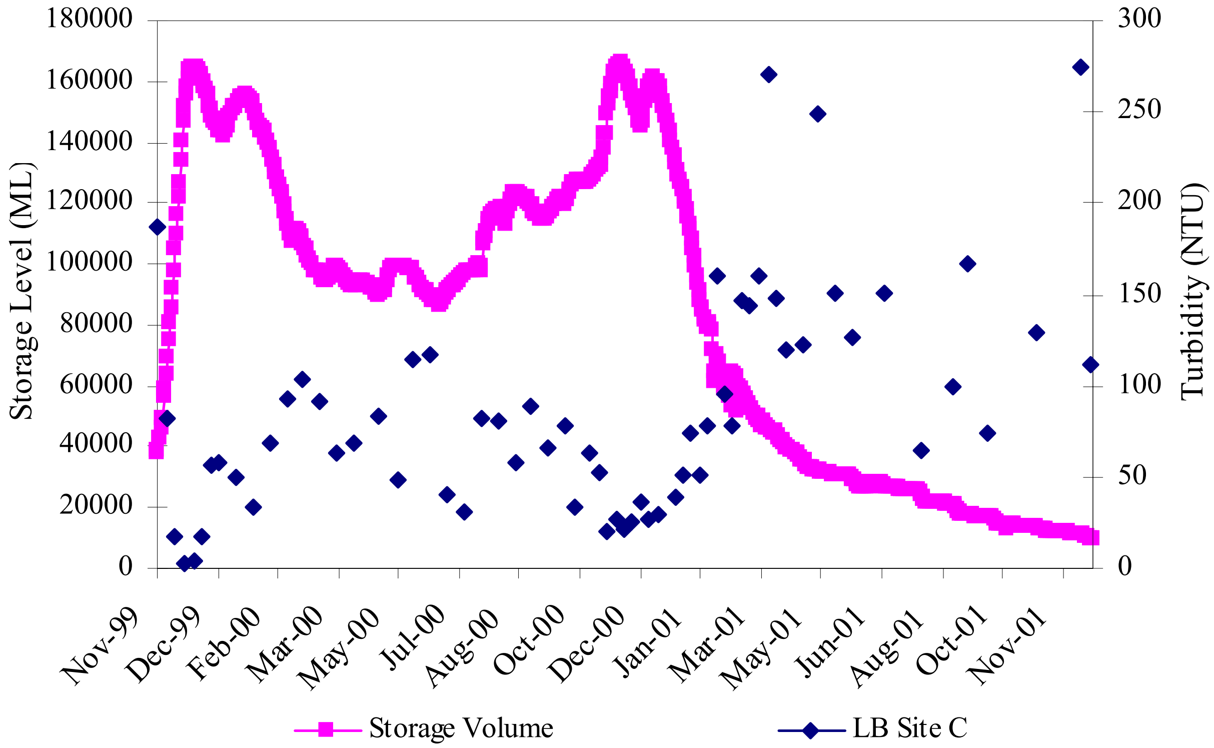


Figure 34. Lake Brewster storage level and turbidity at Lake Brewster site C, 1999 - 2001

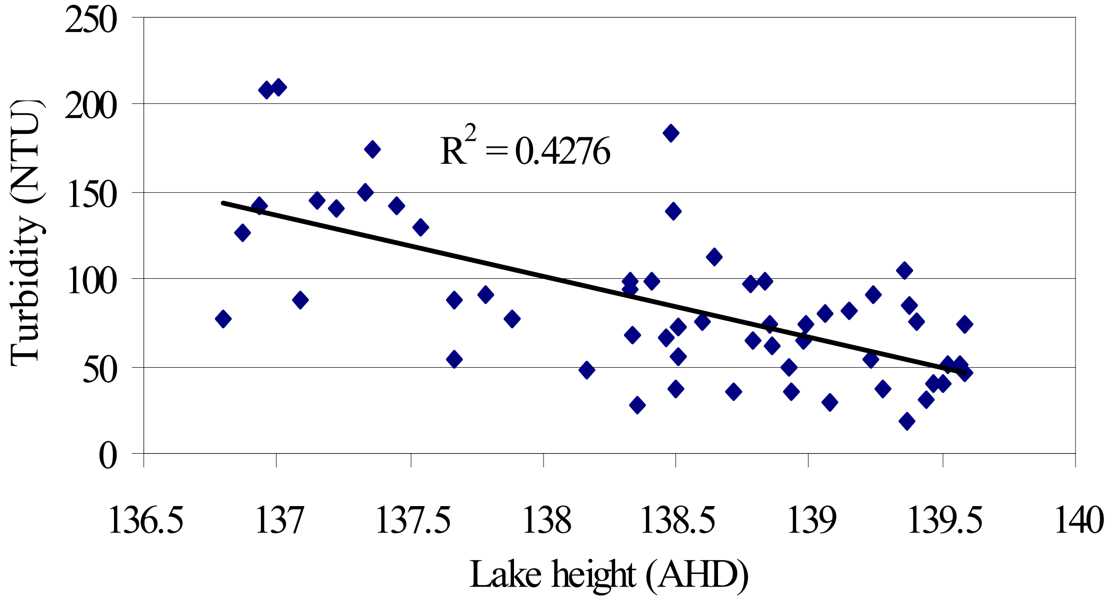


Figure 35 Relationship between turbidity and Lake height at Lake Brewster site B, 1999 – 2002.

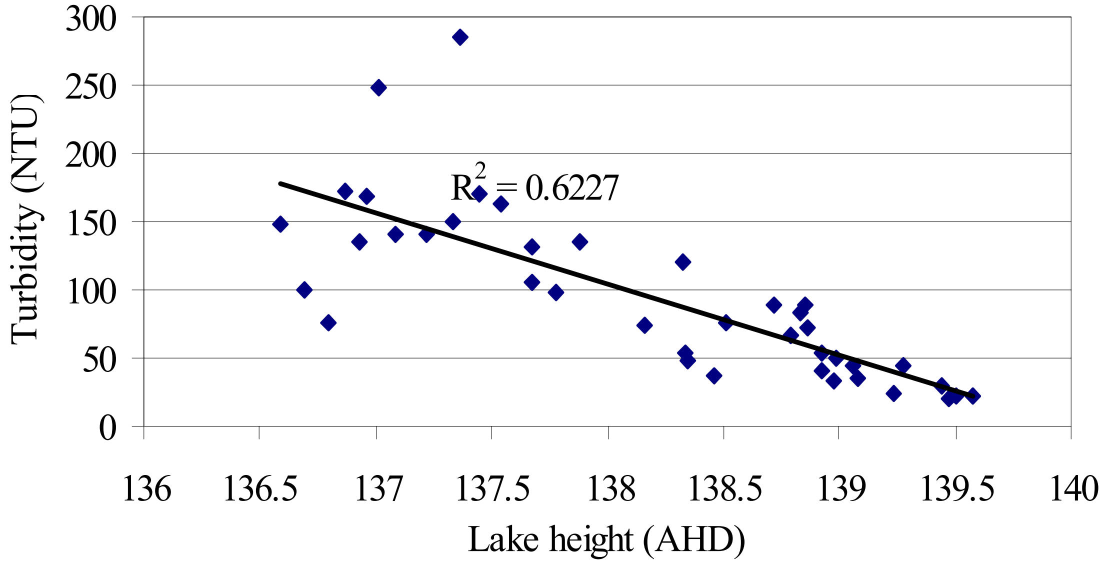


Figure 36. Relationship between lake height and turbidity of water released from Lake Brewster, 1999 – 2001

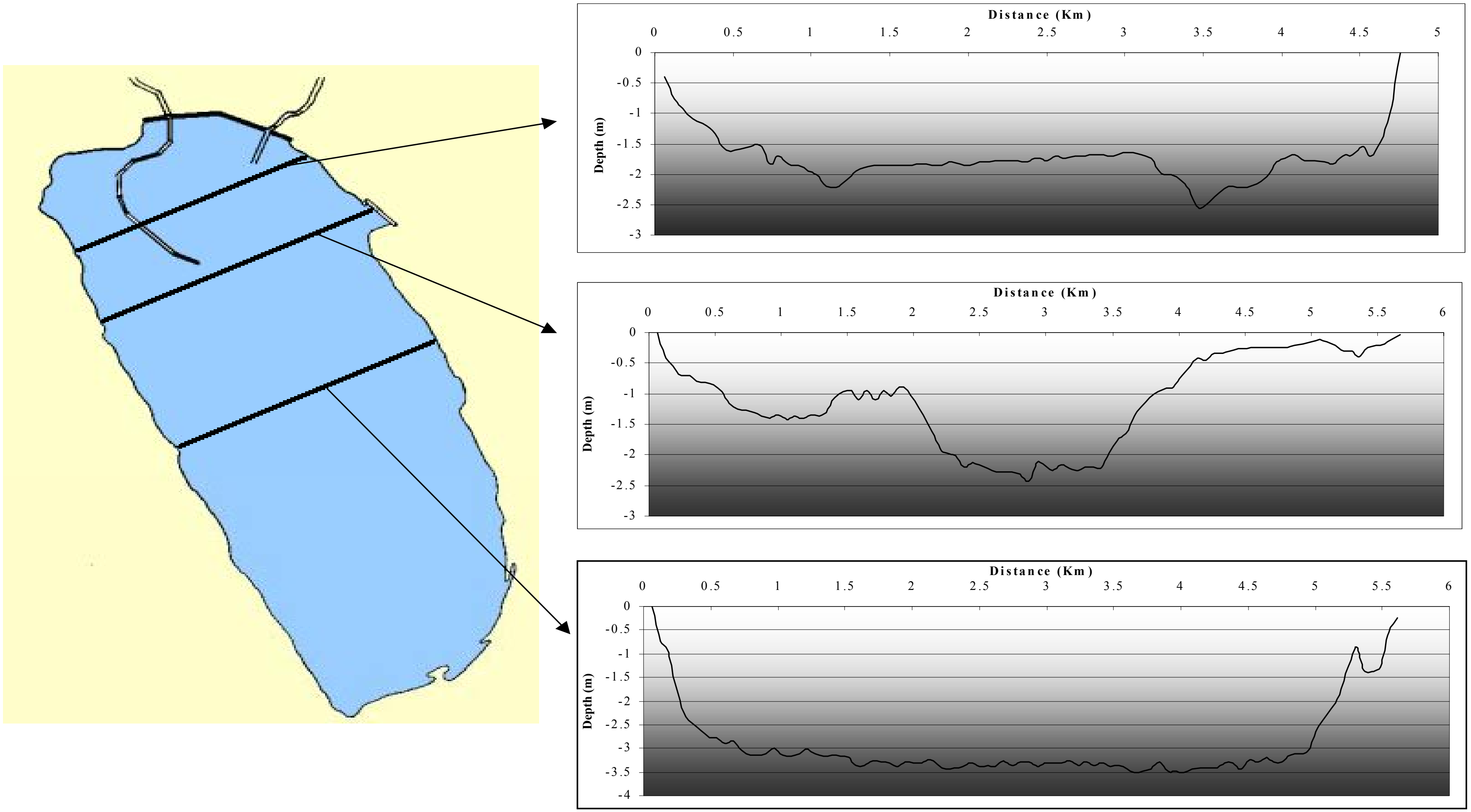


Figure 37. Lake Brewster basin profiles

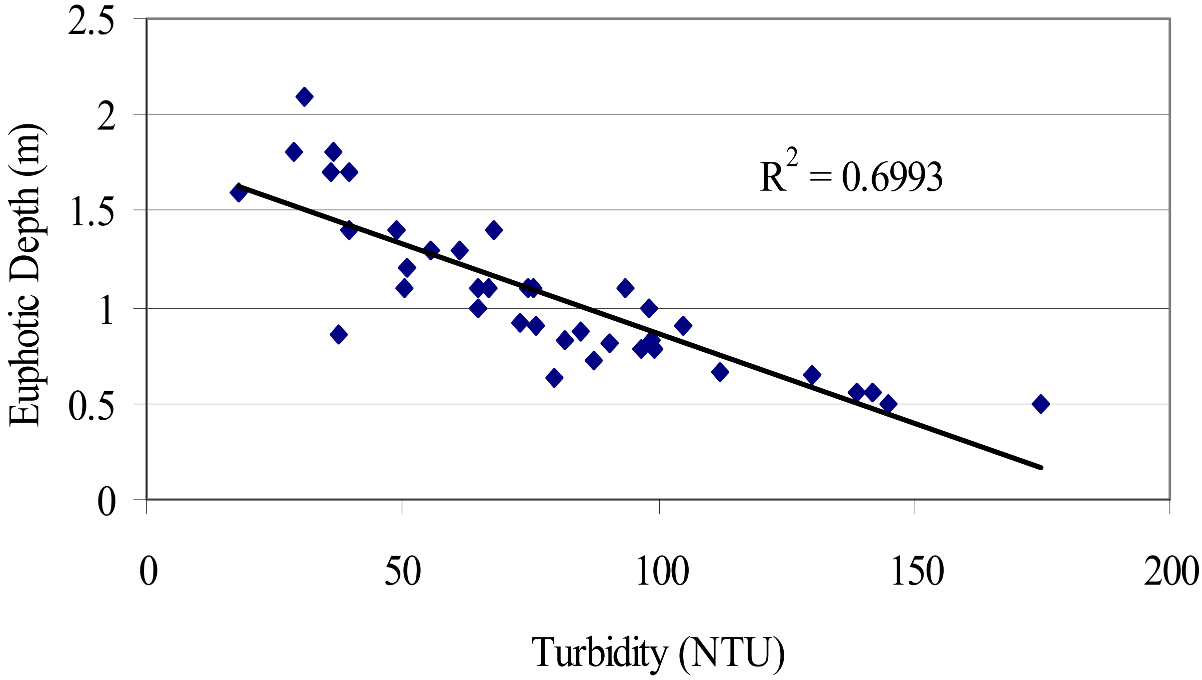


Figure 38. Relationship between turbidity and light penetration as euphotic depth at Lake Brewster, 1999 -2001

3.4 NUTRIENTS

3.4.1 Lake Cargelligo

Nutrient availability, particularly nitrogen and phosphorus, are important factors regulating algal growth. Nutrients become available to algae through a number of pathways. In the case of the Lower Lachlan, the main pathways are upstream sources, resuspension of sediment from both stream channels and lake substrates, and recycling of nutrients by microbial processes.

Nitrate was measured at all sites throughout the study to investigate the relationship between nitrate concentrations in the Lakes and possible increases in river concentrations downstream of the lakes. The relationship between nitrate and blue-green algal populations was also investigated (see Section 3.5).

A summary of nitrate data for Lake Cargelligo sites is displayed in Figure 39 and Appendix 1. There was little difference between median nitrate concentrations in the Lachlan River and Lake Cargelligo sites (Figure 39). There was a greater range of concentrations at Lake Cargelligo site B (centre of lake) compared to other lake sites (Figure 39). These variations may relate to shifting algal populations as a result of wind influences in the open water area of the lake. The large algal populations frequently found in Lake Cargelligo may also impact on concentrations of available nutrients such as nitrate (see Section 3.5).

Apart from the possible impact of algal populations on nitrate, temperature and an increase in metabolic processes within a water body may also influence nitrate concentrations in water. The division of nitrate summary data into winter and summer shows median concentrations are much higher, and the spread of concentrations much greater, in the winter when compared to the summer (Figures 40 and 41). Median concentrations remain below 0.025 mg/L at all sites during the warmer months (Figure 41). Therefore, nitrate concentrations may be simultaneously reduced by algal populations, increasing water temperature and the associated increase in metabolic processes. These seasonal differences did not occur in other measured nutrients.

In terms of indicative nutrient concentrations for the protection of modified aquatic ecosystems, trigger values have been suggested in recent water quality guidelines (ANZECC and ARMCANZ 2000). The trigger values have been derived from reference data collected throughout Australia and New Zealand (ANZECC and ARMCANZ 2000). A measurable perturbation in disturbed ecosystems has been defined using the 80th percentile from the reference data (ANZECC and ARMCANZ 2000). Concentrations above these trigger values may be considered detrimental to ecosystem health for a variety of reasons, including the promotion of algal blooms.

The nitrogen oxides trigger value for freshwater lakes and reservoirs in South-East Australia is 0.01 mg/L (ANZECC and ARMCANZ 2000). The nitrogen oxides trigger value for lowland rivers in South-East Australia is 0.04 mg/L (ANZECC and ARMCANZ 2000). Lake Cargelligo, Curlew Water and Sheet of Water exceeded the storage trigger value around 55% of the time. Lake Cargelligo Weir, downstream of Lake Cargelligo Weir and Murrin Bridge all exceeded the nitrate trigger value for lowland rivers around 30 % of the time. Lake Creek, Lake Cargelligo outlet, exceeded river trigger values 10% of the time.

Filterable reactive phosphorus is a component of total phosphorus and represents an estimate of immediately available phosphorus to aquatic plants and algae. Median filterable reactive phosphorus concentrations were lower in Lake Cargelligo than concentrations found in the Lachlan River. This observation may relate to large algal populations utilising available nutrients or may indicate the diffusion of available phosphorus back into the sediment (Figure 42) (see Section 3.5). Available phosphorus was around 10% of total phosphorus concentrations which is comparable to other Australian shallow, inland lakes (Halliwell and O'Shanassy 1997).

The filterable reactive phosphorus trigger value for freshwater lakes and reservoirs in South-East Australia is 0.005 mg/L (ANZECC and ARMCANZ 2000). The filterable reactive phosphorus trigger value for lowland rivers in South-East Australia is 0.02 mg/L (ANZECC and ARMCANZ 2000). Lake Cargelligo exceeded the trigger value 47% of the time, while Curlew Water and Sheet of Water exceeded the storage trigger value around 65% of the time. Lake Cargelligo Weir, downstream of Lake Cargelligo Weir and Murrin Bridge all exceeded the filterable reactive phosphorus trigger value for lowland rivers around 14% of the time. Lake Creek, Lake Cargelligo outlet, exceeded river trigger values 7% of the time.

The measurement of total nitrogen and total phosphorus indicate the amount of nutrients in the water column that, over time and under various conditions, may become available to aquatic plants and algae. In the case of nitrogen, some may be lost to the system in the form of N_2. Total nitrogen concentrations steadily increased from the lake inlet to the outlet, with higher concentrations in Lake Creek than those found in the river (Figure 43, Appendix 1). Increases also occurred in total phosphorus concentrations at Lake Creek (Figure 44, Appendix 1). Though total nutrients appear to be slightly higher in Lake Cargelligo and its outlet, the sporadic and proportionally small releases from the lake result in no significant impact on average river nutrient concentrations downstream of the outlet (Figures 43 and 44).

The trigger values for freshwater lakes and reservoirs in South-East Australia are 0.35 mg/L for total nitrogen and 0.01 mg/L for total phosphorus (ANZECC and ARMCANZ 2000). Trigger values for lowland rivers in South-East Australia are 0.5 mg/L for nitrogen and 0.05 mg/L for total phosphorus (ANZECC and ARMCANZ 2000). All Lake Cargelligo storage sites (including Curlew Water and Sheet of Water) exceeded the total nitrogen and total phosphorus trigger values 100% of the time. Lake Cargelligo Weir and downstream of Lake Cargelligo Weir exceeded the total nitrogen trigger value around 70% of the time, and exceeded the total phosphorus trigger value about 50% of the time. The Lachlan River at Murrin Bridge and Lake Creek exceeded the lowland river total nitrogen trigger value 80% and 100% of the time, respectively. Both sites exceeded the total phosphorus trigger value 90% of the time.

Available nutrients measured in the Lachlan River exceeded trigger values less frequently than in Lake Cargelligo and its associated storages. The level of exceedance is reasonably high in the storages and, therefore, may be at levels that promote algal blooms. Lake Creek had the lowest exceedance of available nutrients and may indicate the depletion of filterable reactive phosphorus and nitrate in the storages. Total nutrients were generally above recommended trigger values in the storages, Lake Creek and the Lachlan River at Murrin.

Total carbon and total organic carbon were sporadically measured at all sites in Lake Cargelligo. Figure 45 shows a dramatic reduction in total carbon concentrations from about January 2002, while total organic carbon concentrations remained constant. Carbon may have been utilised by algal populations in Lake Cargelligo over summer (see section 3.5). Concentrations of both variables were very similar over the sampling period at all sites within Lake Cargelligo, however the lack of data points make the changes in total carbon concentrations difficult to interpret.

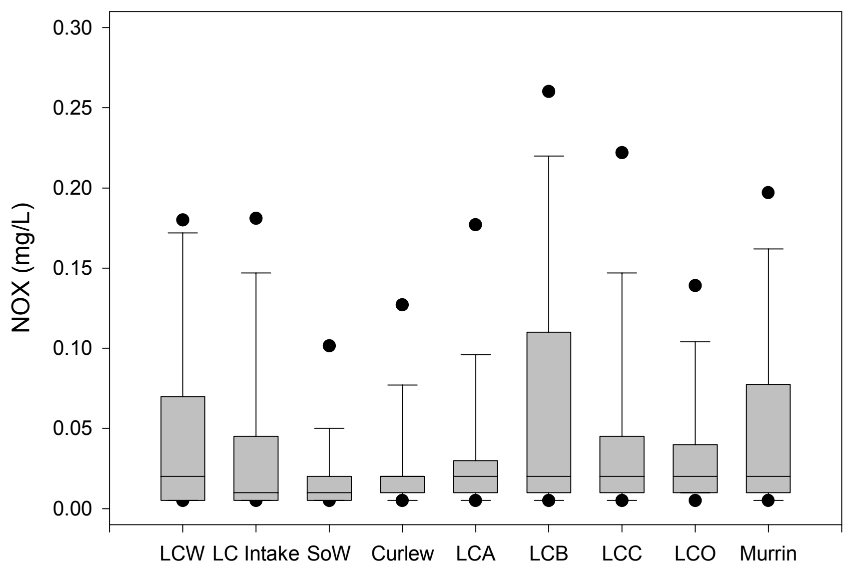


Figure 39. All nitrate concentrations from Lake Cargelligo Weir to Murrin Bridge, 1999 – 2002

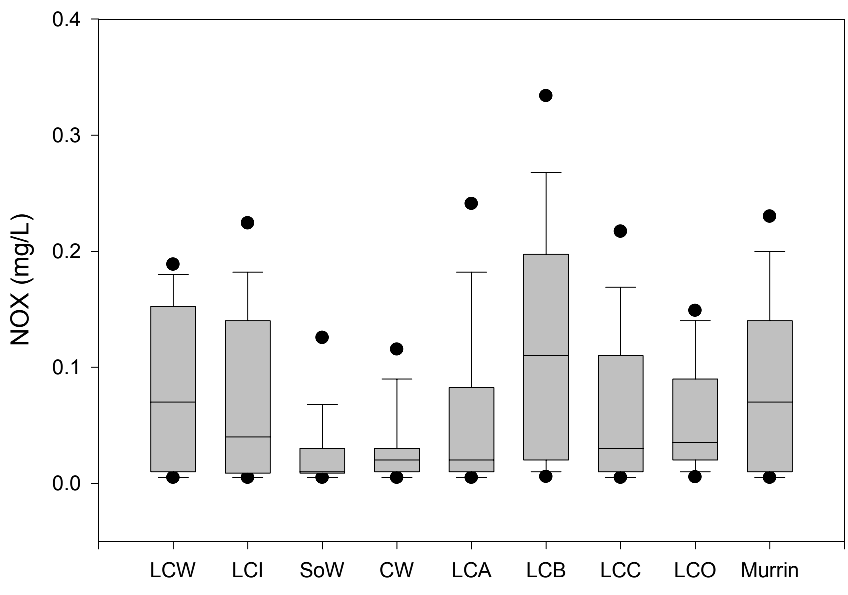


Figure 40 Nitrate concentrations from Lake Cargelligo Weir to Murrin Bridge in autumn/winter, 1999 – 2002

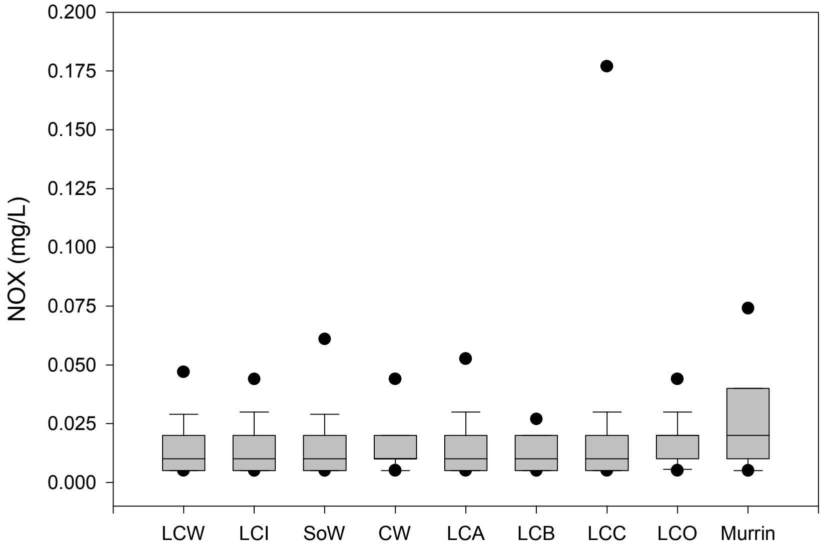


Figure 41 Nitrate concentrations from Lake Cargelligo Weir to Murrin Bridge in spring/summer, 1999 – 2002

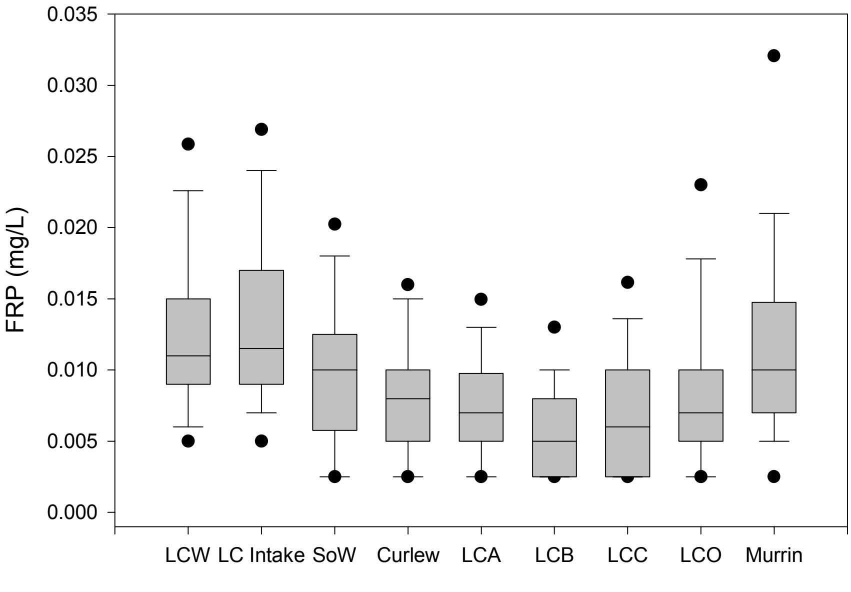


Figure 42. Filterable reactive phosphorus concentrations from Lake Cargelligo Weir to Murrin Bridge, 1999 – 2002

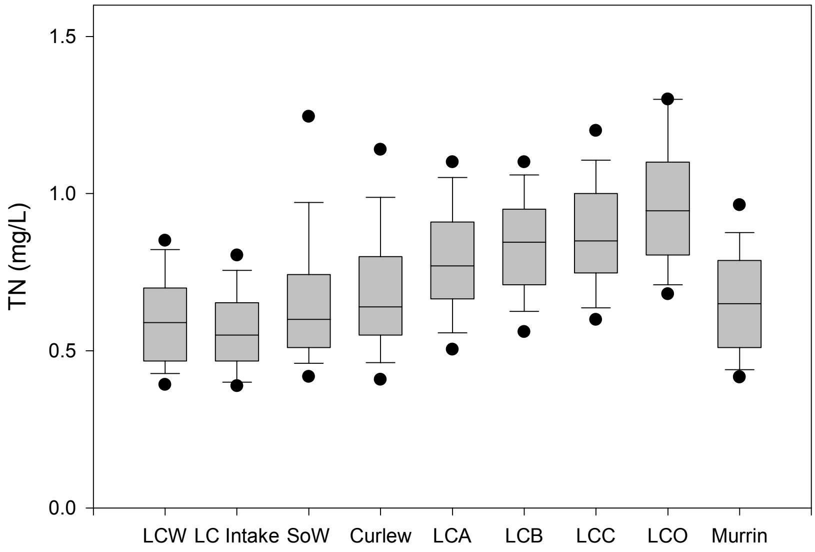


Figure 43. Total nitrogen concentrations from Lake Cargelligo Weir to Murrin Bridge, 1999-2002

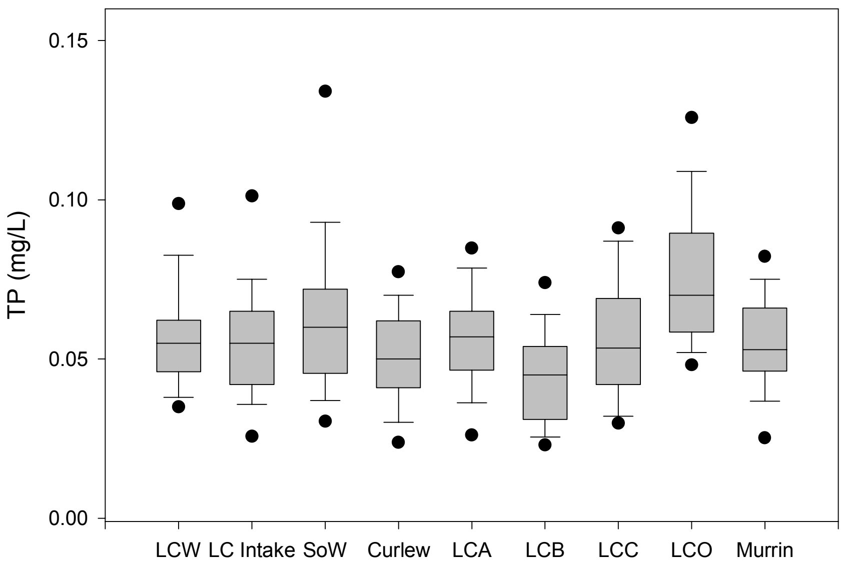


Figure 44. Total phosphorus concentrations from Lake Cargelligo Weir to Murrin Bridge, 1999 – 2002

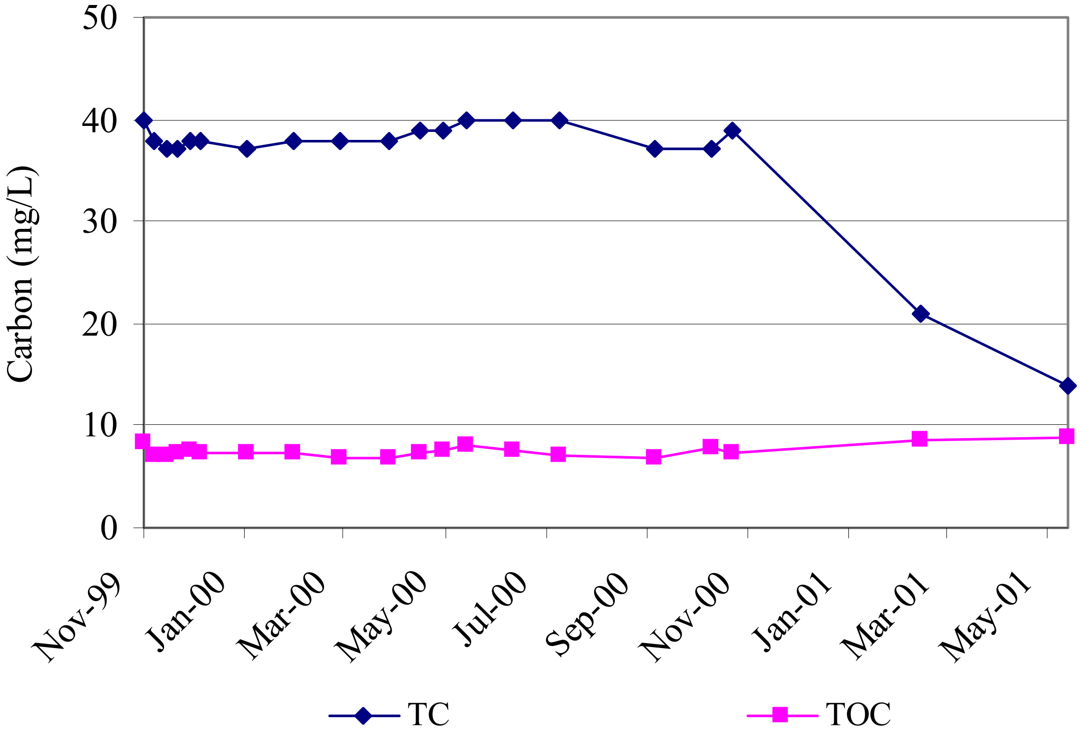


Figure 45. Lake Cargelligo site B total carbon and total organic carbon concentrations, 1999 - 2001

3.4.2 Lake Brewster

Nitrate concentrations were not significantly different between the Lachlan River and Lake Brewster sites (Figure 46, Appendix 1). Nitrate concentrations were less variable in Lake Brewster when compared to Brewster Weir (Figure 46). This may be the result of greater biological activity in the less turbid weir or changing river inflows. However, seasonal patterns of nitrate concentrations show a considerable difference between winter and summer, as was the case with Lake Cargelligo sites (Figures 47 and 48). Nitrate concentrations are higher and more variable in the cooler months, particularly at sites most influenced by the river (Figures 47 and 48). Concentrations at storage sites tended to stay at similar levels through the summer and winter (Figures 47 and 48). This may indicate the impact temperature change has on biological activity in the river-influenced sites when compared to the lake sites.

Filterable reactive phosphorus concentrations were similar in river and lake sites (Figure 49). Concentrations were found to be less variable than nitrate, with no seasonal patterns evident (Figure 49). The lack of variability in filterable reactive phosphorus concentrations across the sites indicate that it was not driving algal blooms in Lake Brewster (see Section 3.5).

Comparisons between available nutrient trigger values and measured concentrations in the Lower Lachlan indicate river sites were exceeding the nitrate trigger about 20% of the time and the filterable reactive phosphorus trigger about 10% of the time. Lake sites were exceeding nitrate and filterable reactive phosphorus trigger values about 70% of the time.

Large differences between median total nitrogen and phosphorus concentrations were found within Lake Brewster when compared to sites upstream of the lake (Figures 50 and 51, Appendix 1). Lake Brewster outlet had the highest median nutrient concentrations for both total nitrogen and total phosphorus, and Lake Brewster Weir the lowest (Figures 50 and 51). Willandra Weir, while not considerably higher than upstream sites, tended to have more variable nutrient concentrations than in the river upstream (Figures 50 and 51). No seasonal differences were detected over the study period.

The comparison of total nutrient concentrations in the Lachlan River at Brewster Weir and downstream of Brewster Weir with default trigger values, indicates total nitrogen values were exceeded 80% and total phosphorus values exceeded 40% of the time. The Lachlan River at Willandra Weir, downstream of Lake Brewster outlet, exceeded total nitrogen and total phosphorus values 96% and 100% of the time, respectively. Lake Brewster sites exceeded total nutrient trigger values 97% to 100% of the time.

The release of water with high nutrient concentrations can have a significant impact upon the water quality of the Lower Lachlan. The influence and seasonal variation of total nutrient concentrations from Lake Brewster on Willandra Weir is demonstrated in Figures 52 and 53. A peak in nutrient concentrations occurred at Willandra Weir in March 2001, with a corresponding peak at Lake Brewster outlet (Figures 52 and 53). This peak may be related to the low storage level increasing the exposure of lake sediments to increased wave action and therefore increasing suspended solids and attached nutrients in the water column (see section 3.3 and 3.5). There was also an increase in the algal population during March 2001 (see section 3.5).

The magnitude of the influence from Lake Brewster storage is dependent on the proportion of total flow the storage contributes at Willandra Weir. Early in March, Willandra Weir received approx. 65% of its flow from Lake Brewster (Figure 54). Water from Lake Brewster had much higher nutrient concentrations than water from the Lachlan and, as a result, nutrient concentrations at Willandra Weir began to rise (Figures 52, 53 and 54). Nutrient concentrations at Willandra Weir peaked in mid March, however, as the proportion of flow received from Lake Brewster at Willandra Weir began to decrease, so did nutrient concentrations (Figures 52, 53. and 54).

Nutrient concentrations in Lake Brewster storage peaked in mid May but by that time only 14 % of the water reaching Willandra Weir came from Lake Brewster (Figure 54).

Carbon may also be a limiting factor for algae. In Lake Brewster total carbon concentrations dropped significantly around February 2001 (Figure 55), with a corresponding drop in organic carbon for a shorter time (Figure 55). This may be from the utilisation of carbon by a large algal population present in the Lake over late summer (see Section 3.5).

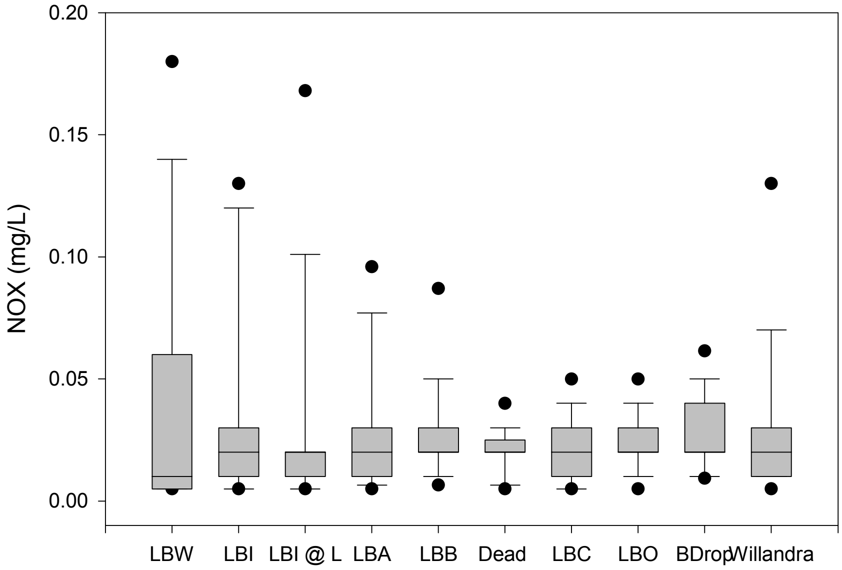


Figure 46. Nitrate concentrations at Lake Brewster sites, 1999 – 2002

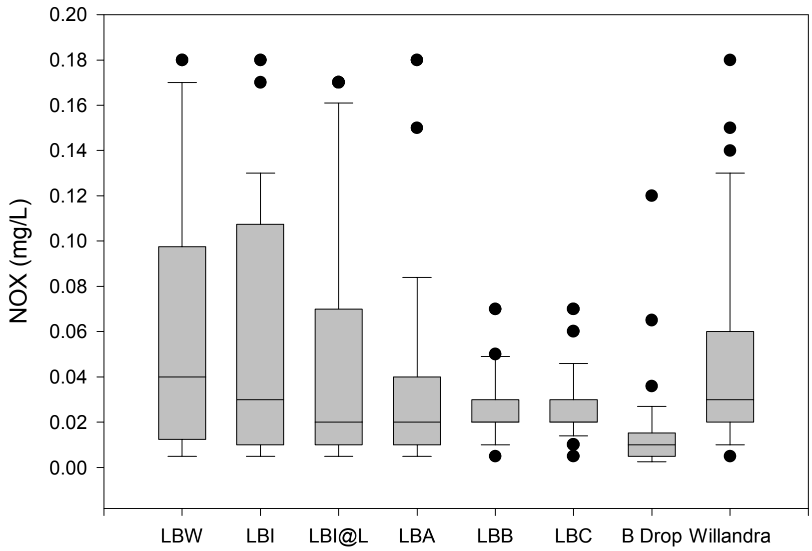


Figure 47. Nitrate concentrations at Lake Brewster sites in Autumn/Winter, 1999 – 2002

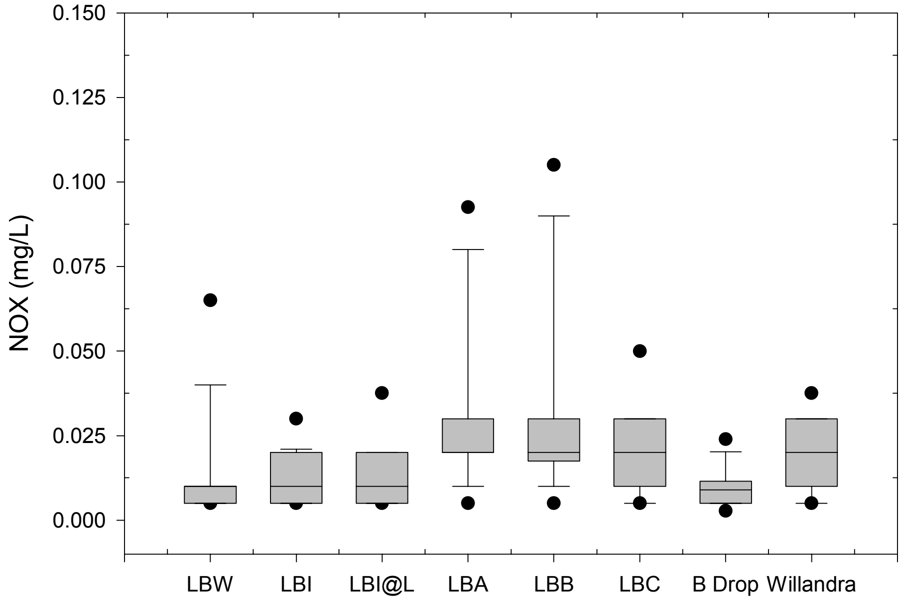


Figure 48 Nitrate concentrations at Lake Brewster sites in Spring/Summer, 1999 – 2002

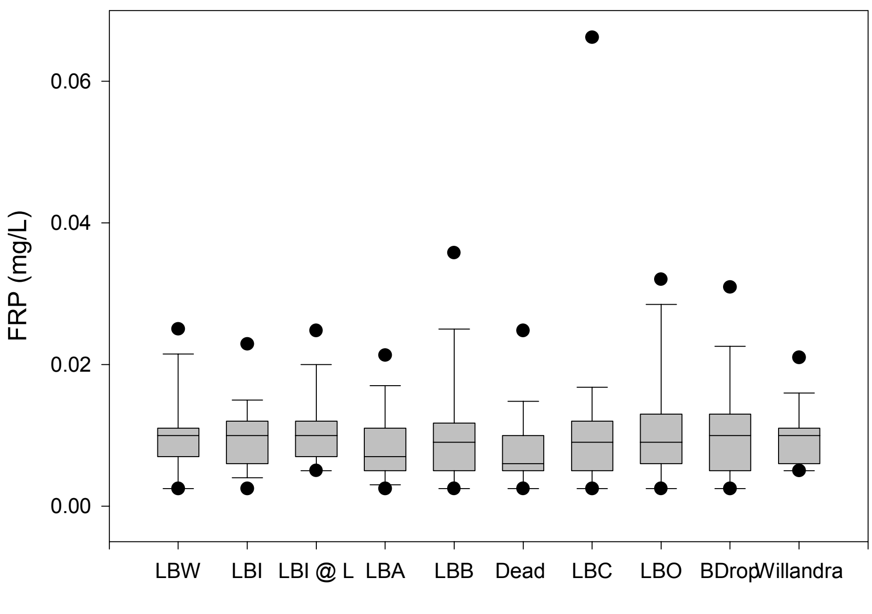


Figure 49. Filterable reactive phosphorus concentrations at Lake Brewster sites, 1999 – 2002

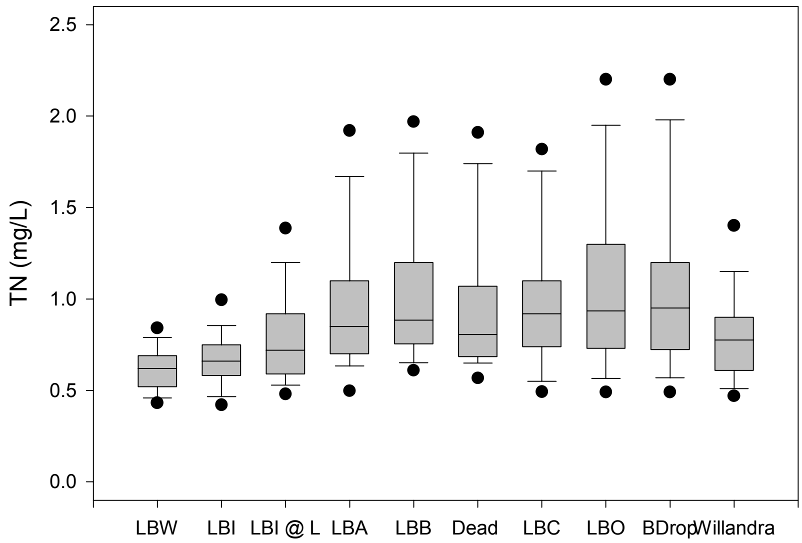


Figure 50. Total nitrogen concentrations at Lake Brewster sites, 1999 - 2002

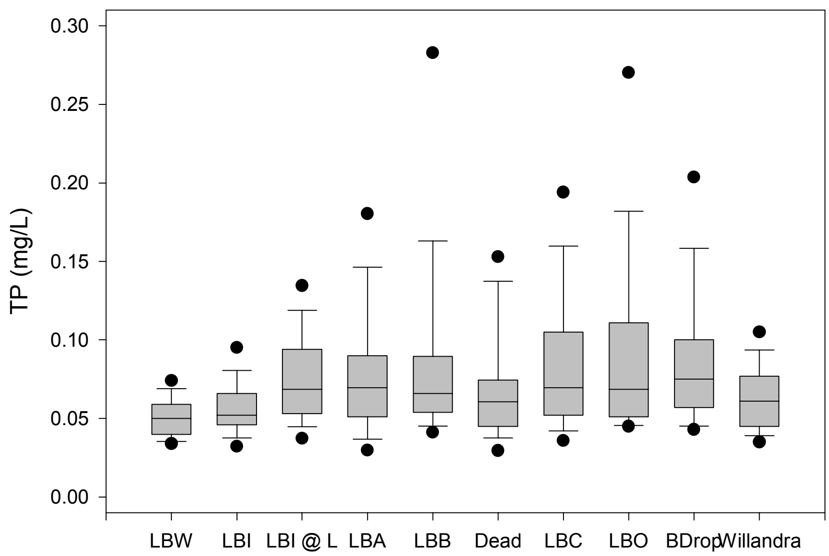


Figure 51. Total phosphorus concentrations at Lake Brewster sites, 1999-2002

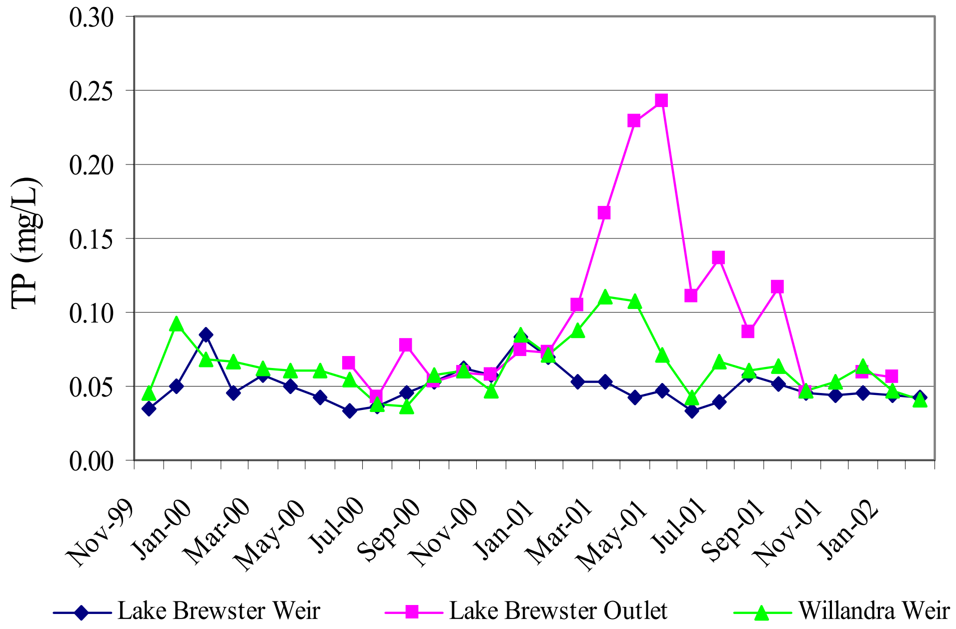


Figure 52. Total phosphorus concentrations in Lake Brewster Weir, Lake Brewster Outlet and Willandra Weir, 1999 – 2002

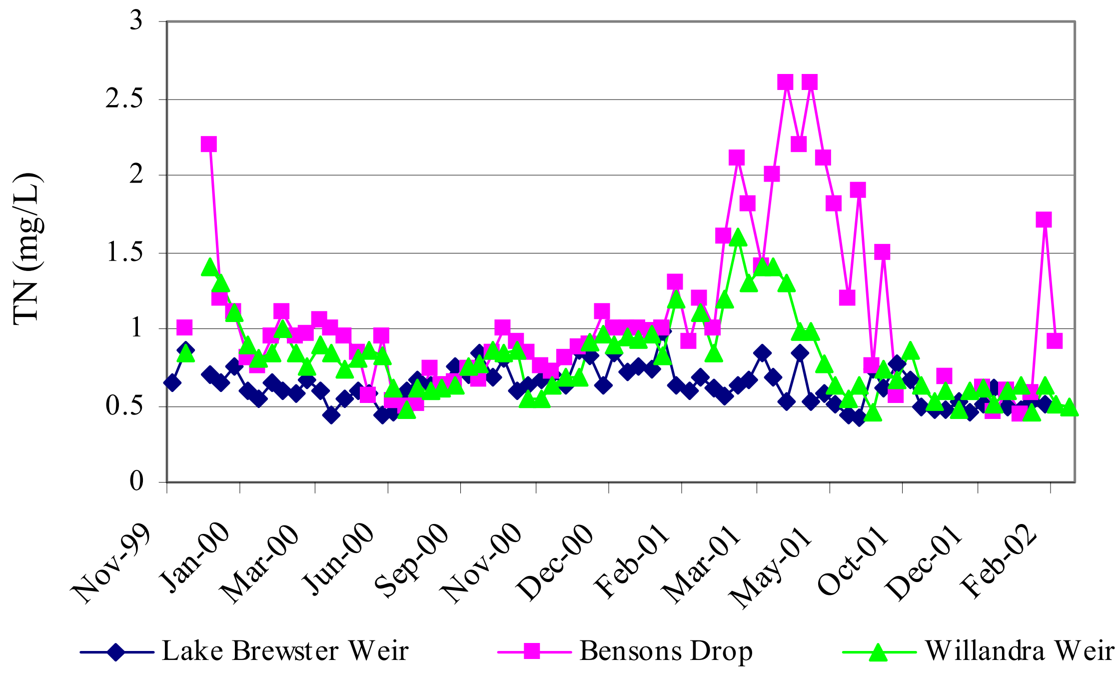


Figure 53. Total nitrogen concentrations in Lake Brewster Weir, Lake Brewster outlet and Willandra Weir, 1999 – 2002

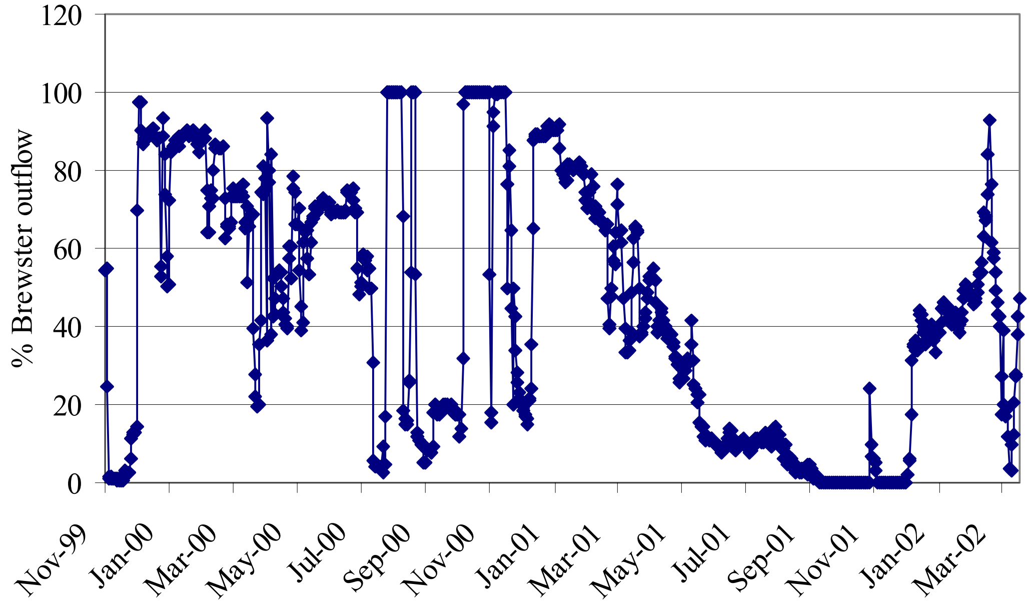


Figure 54. Proportion of flow from Lake Brewster storage received at Willandra Weir, February 2001 to July 2001

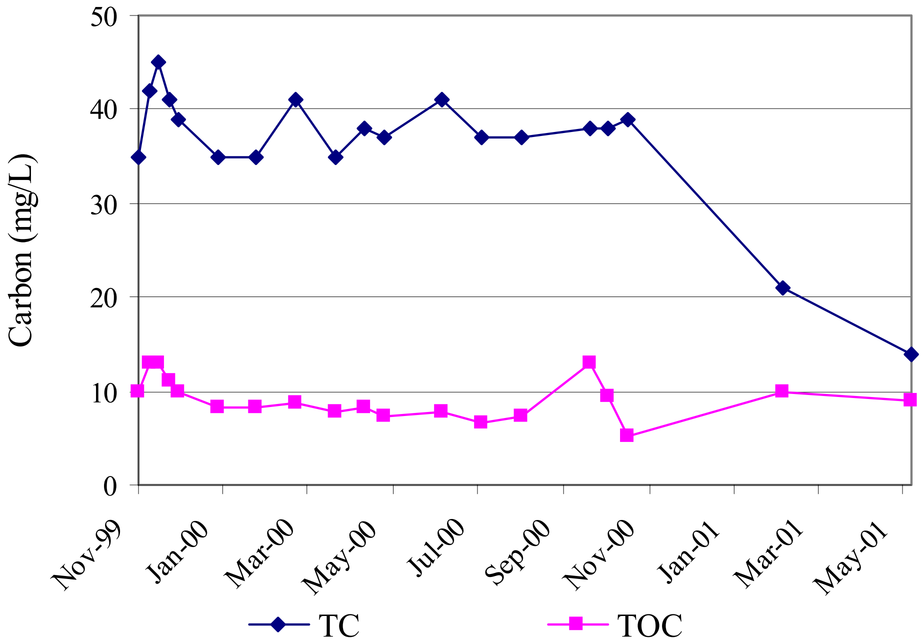


Figure 55. Lake Brewster site C total carbon and total organic carbon concentrations, 1999 – 2001.

3.4.3 Sediments and nutrients

The release and uptake of nutrients, particularly phosphorus, from sediments plays a key role in the nutrient dynamics of a water body. There are a number of pathways for phosphorus to enter the water column from sediments, these include:

- Anaerobic mobilisation of phosphorus - under aerobic conditions phosphorus in lakebed sediments is immobilised by iron. When conditions become anoxic, phosphorus is released (Scheffer 1998). This process is particularly important for storages where the hypolimnion becomes anoxic under stratification or where anoxic sediments release phosphorus into interstitial pore waters and a gradient then allows the release of pore water to the overlying water column.
- Sediment resuspension - Sediments can act as an internal source of nutrients (Luettich, R. Jr *et al.* 1990). Phosphorus and other nutrients accumulate in lakebed sediments driven by the decomposition of dead organic material (Scheffer 1998). Resuspension of sediments either by wind driven wave action or bioturbation may reintroduce these nutrients to the water column.

Increased internal phosphorus loading from the periodic wetting and drying of the lakebed impacts upon the adsorption and release of phosphorus by sediments. The rate of phosphorus released from sediments is increased following drying and then re-flooding compared with sediments that remain wet (Qui & McComb 1994). This is further enhanced by anaerobic conditions that can be brought about by decaying vegetation.

A clear relationship between the concentration of total nutrients and suspended solids is apparent in Figures 56 and 57. When suspended solid concentrations were low, nutrient concentrations were low and as suspended solid concentrations increased, so too did nutrient concentrations (Figures 56 and 57). The concentration of nutrients in the water column can significantly impact upon other lake processes such as algal numbers. An increase in suspended solids can raise nutrient concentrations, which then influences algal growth, provided light is not limited. Both phosphorus and nitrogen increased in Lake Brewster during March 2001 as the lake was drawn down (see section 3.4.2). Nitrogen:phosphorus ratios at Lake Brewster site B shows phosphorus concentrations increase considerably in proportion to nitrogen following March 2001, which was also around the time of significant algal growth (Figure 58).

A lot of debate surrounds the usefulness of nitrogen:phosphorus (N:P) ratios in relation to predicting algal populations. There is uncertainty with regard to the importance of total nutrient ratios compared to absolute nutrient values or the ratio of bio-available nutrients (Pick and Lean 1987). Studies investigating N:P ratios usually consider waterbodies with a ratio above 16:1 as phosphorus deficient, while those with ratios below 16:1 are considered phosphorus enriched. Within Lake Brewster the ratio is generally close to the 16:1 ratio considered 'normal', however an interesting relationship developed between decreasing N:P ratios and an increasing algal population (Figure 59). The change in ratio may have been a significant contributing factor to the algal bloom or may just reflect that large algal biomass present. Algal numbers could also have been responding to other stimuli such as an increase in water temperature and pH (see Section 3.5).

Lake Brewster storage capacity was drawn down to below 50 000 ML from February to November 1999 resulting in a mostly dry lake bed. Terrestrial vegetation, particularly weeds such as Noogoora Burr, established. As the storage refilled the terrestrial vegetation was flooded. The decomposition of this organic matter reduced dissolved oxygen concentrations, particularly at site C in November and December 1999 (Figure 60). The increased phosphorus released from dry sediments that were re-wetted, combined with increased phosphorus released under anaerobic conditions (a result of decaying organic matter) led to high concentrations of phosphorus in the water column (Figure 60).

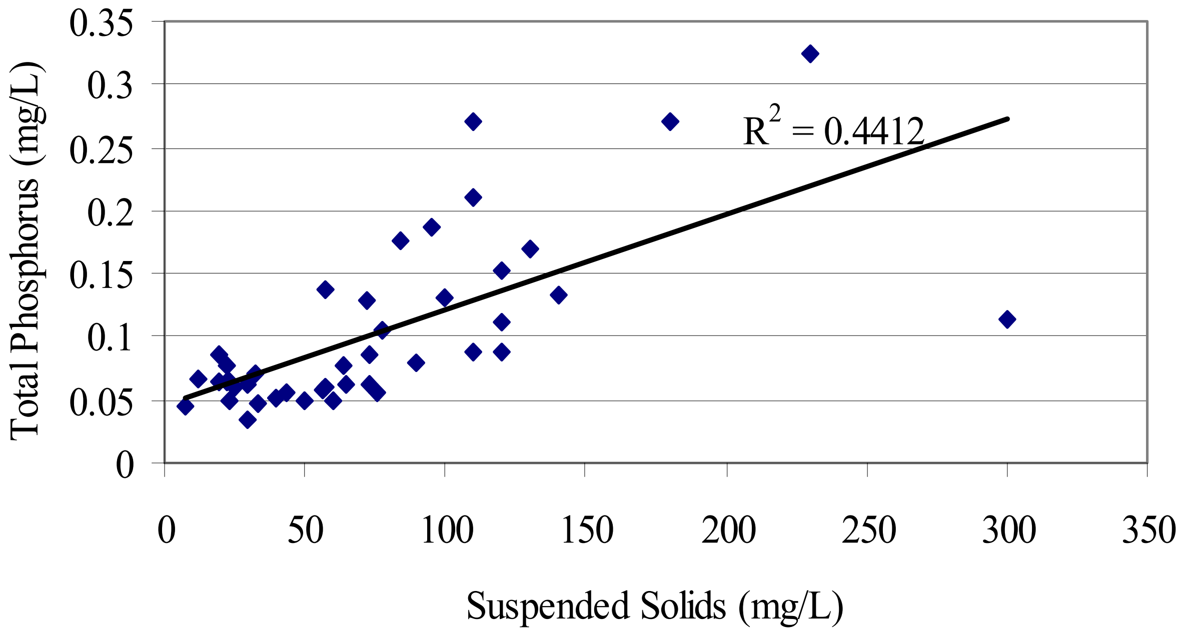


Figure 56. Relationship between suspended solids and total phosphorus at Lake Brewster outlet, 1999 - 2002

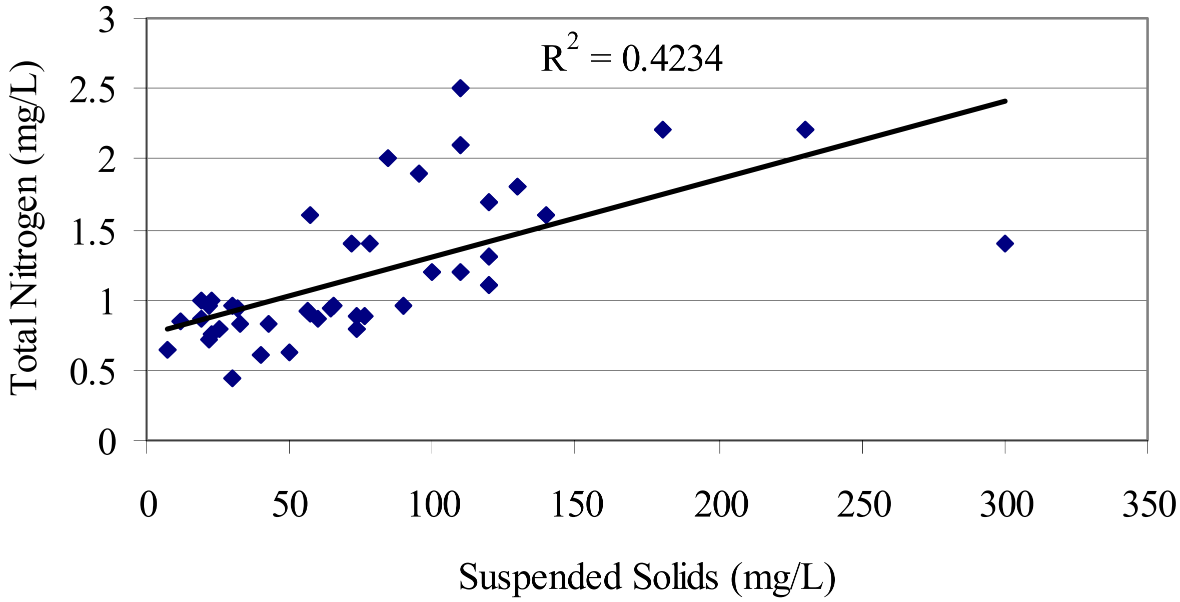
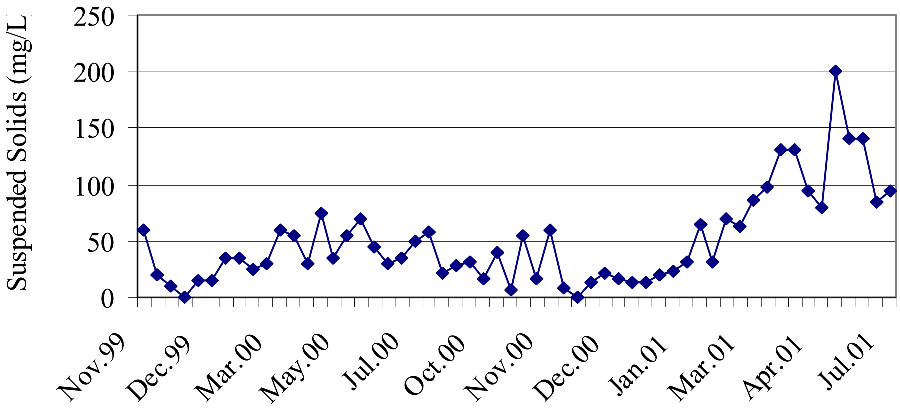
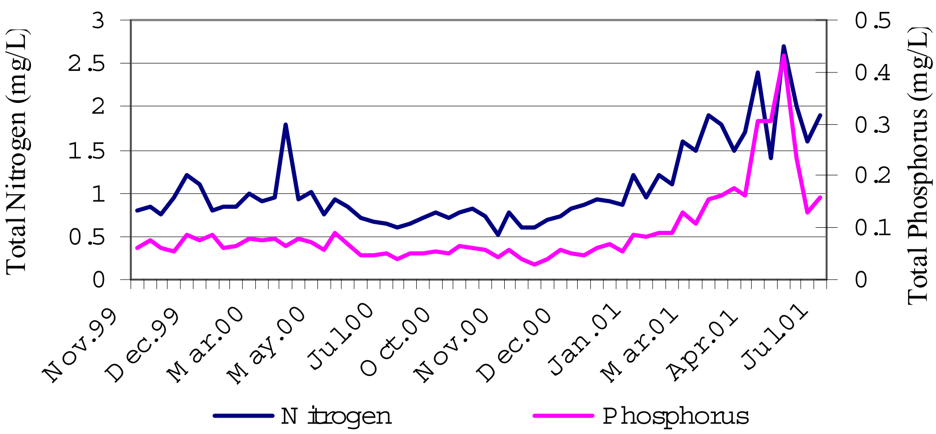


Figure 57. Relationship between suspended solids and total nitrogen at Lake Brewster outlet, 1999 – 2002

a) Suspended Solids - Lake Brewster Site B



b) Nutrient Concentration - Lake Brewster Site B



c) Algae numbers - Lake Brewster Site B

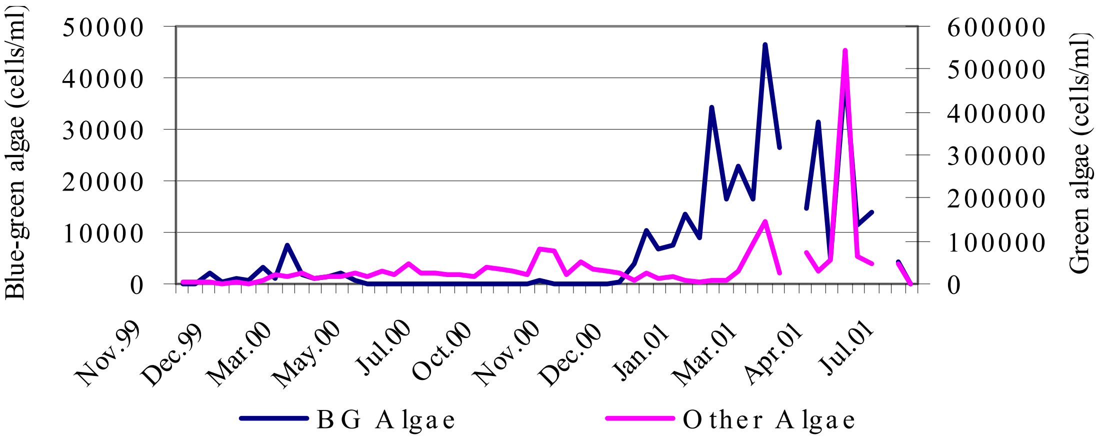


Figure 58. Relationship between (a) suspended solids, (b) nutrient concentration and (c) algal numbers at Lake Brewster site B, 1999 - 2001

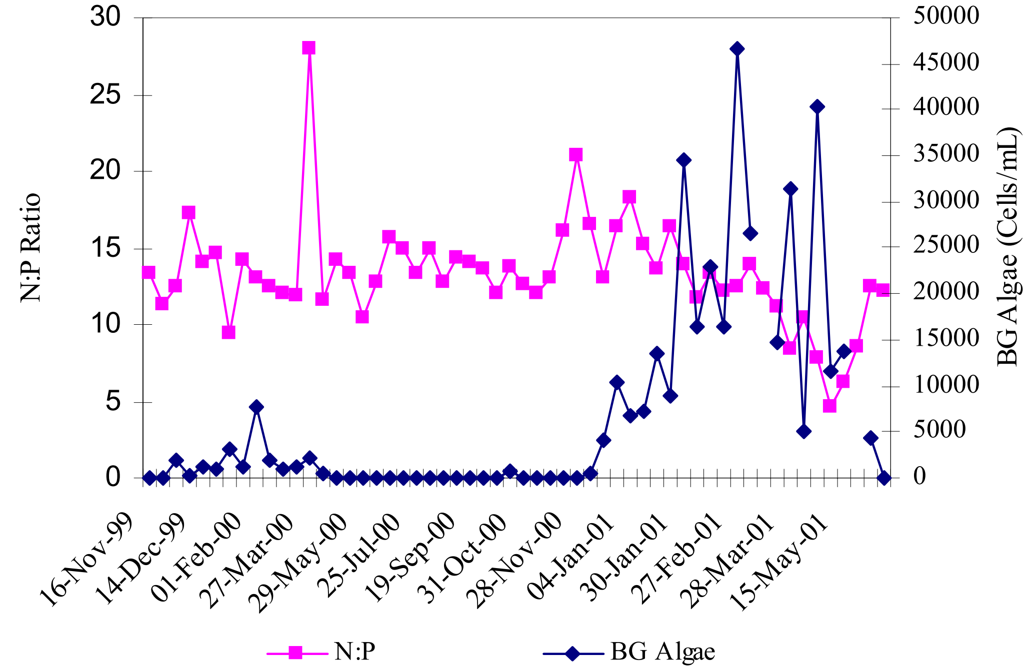


Figure 59. Nitrogen:phosphorus ratio and blue-green algal numbers-at Lake Brewster Site B, 1999 – 2001

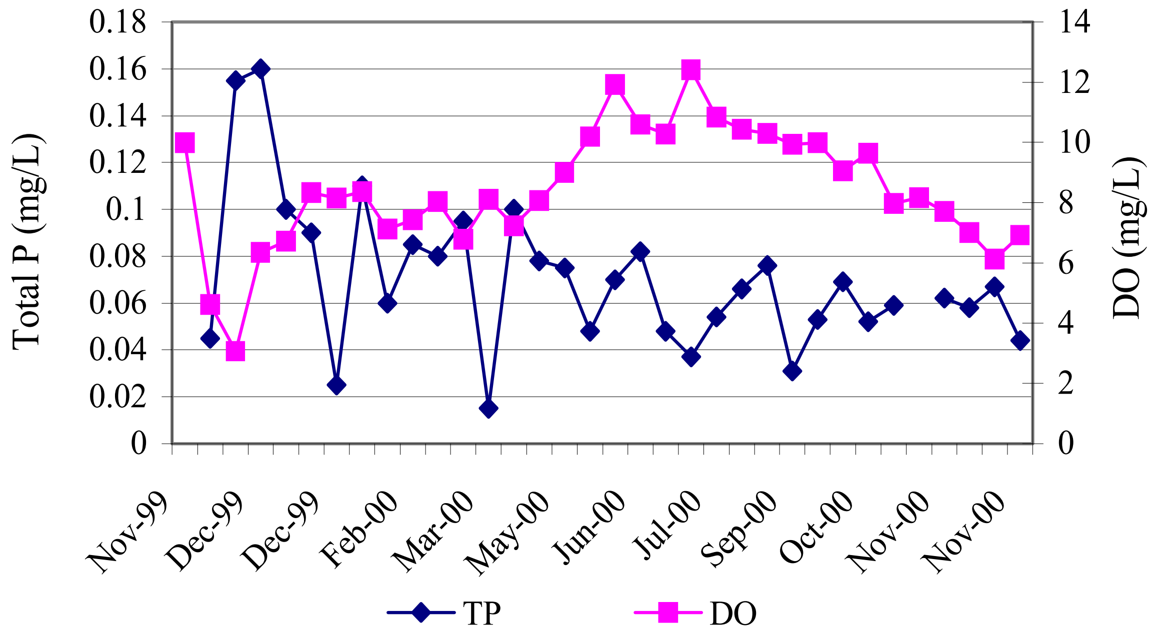


Figure 60 Dissolved oxygen and total phosphorus concentrations in Lake Brewster site C, 1999 – 2000. (Dissolved oxygen measured at lake bottom)

3.5 ALGAE AND AQUATIC VEGETATION

3.5.1 Blue-green algae

Lake Cargelligo and Lake Brewster are susceptible to blue-green algal blooms throughout the warmer months. These algal blooms are not only detrimental to the immediate lake environs, but may also impact the Lower Lachlan River and its users.

Blue-green algal concentrations in Lake Cargelligo were higher and more variable than those in the Lachlan River (Figure 61, Appendix 1). This variability can be attributed to the boom and bust nature of the blue-green algal populations within the lake. Initial blue-green algae seeding of Lake Cargelligo may come from Sheet of Water and Curlew Water, two shallow, turbid water bodies along the inlet channel (Figure 62). Both water bodies have greater protection from wind-action than Lake Cargelligo, which may encourage algal growth when conditions are less favourable in Lake Cargelligo.

Within the Lake Cargelligo system mean blue-green algal numbers indicate seeding from Sheet of Water (Figure 62). Mean numbers increase in Sheet of Water when compared to Lake Cargelligo Weir and further increase in Curlew Water (Figure 62). These two water bodies along the intake channel could be dramatically increasing final blue-green algal populations in Lake Cargelligo (Figure 62), by allowing prior growth of the algae before the water enters Lake Cargelligo itself.

There appeared to be a negative relationship between blue-green algal concentrations and nitrate in Lake Cargelligo (Figure 63). This may be from the utilisation of available nitrogen by algae or high concentrations may pre-empt a bloom. Blue-green algal concentrations did not correlate well with other measured nutrients which indicate they were not a limiting factor in algal growth. High blue-green algal numbers were, however, correlated with pH levels above 8 and water temperatures above about 22 ˚C (Figure 64 and 65). Blue-green algae are reported to respond favourably to high pH levels and temperatures (Shapiro 1990), which frequently existed in Lake Cargelligo (Figures 64 and 65). Photosynthesis by the blooms may also increase pH within the lake.

There was also a large decrease in total carbon levels during the 2001 algal bloom (Figure 66). Inorganic carbon is supplied from the atmosphere and is an inexhaustible resource, however, the supply rate may be outstripped by demand (Scheffer 1998). Unfortunately the lack of carbon data makes it difficult to interpret its decline.

The impact of the higher blue-green concentrations in Lake Cargelligo was limited by the proportion of discharge from the lake (Figures 67 and 68). Figure 67 indicates that high blue-green algal concentrations in Lake Cargelligo outflow does increase concentrations in the Lachlan River at Murrin Bridge but the increase is much less than actual concentrations in the outflow water. This is the result of turbulence in the river dispersing algal populations and dilution of lake discharge by river water.

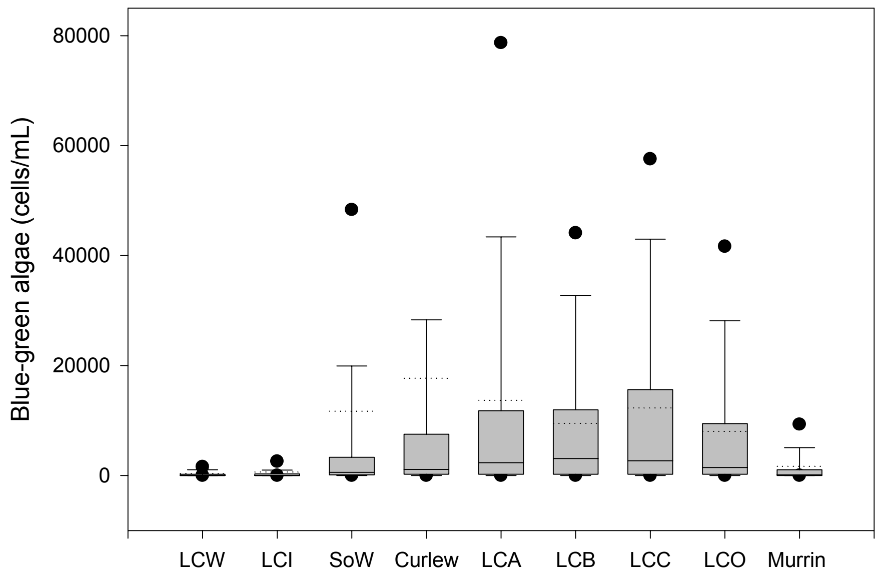


Figure 61. Blue-green algae concentrations at Lake Cargelligo sites, 1999 – 2002.

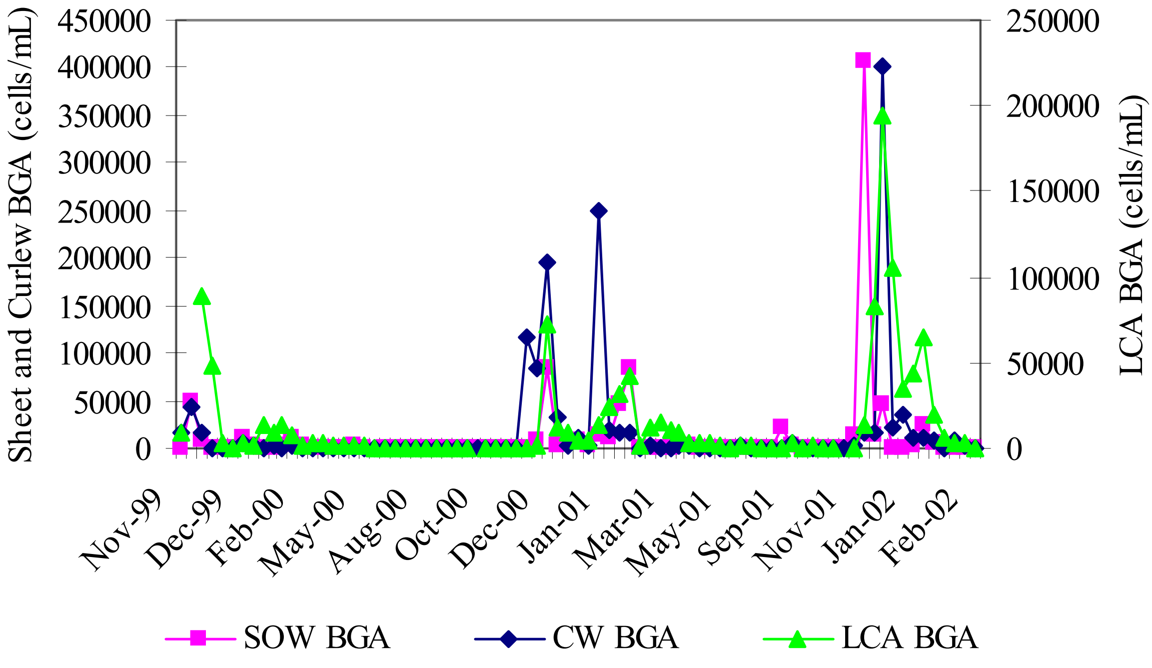


Figure 62. Blue-green algal concentrations at Sheet of Water Curlew Water and Lake Cargelligo site A, 1999 – 2002.

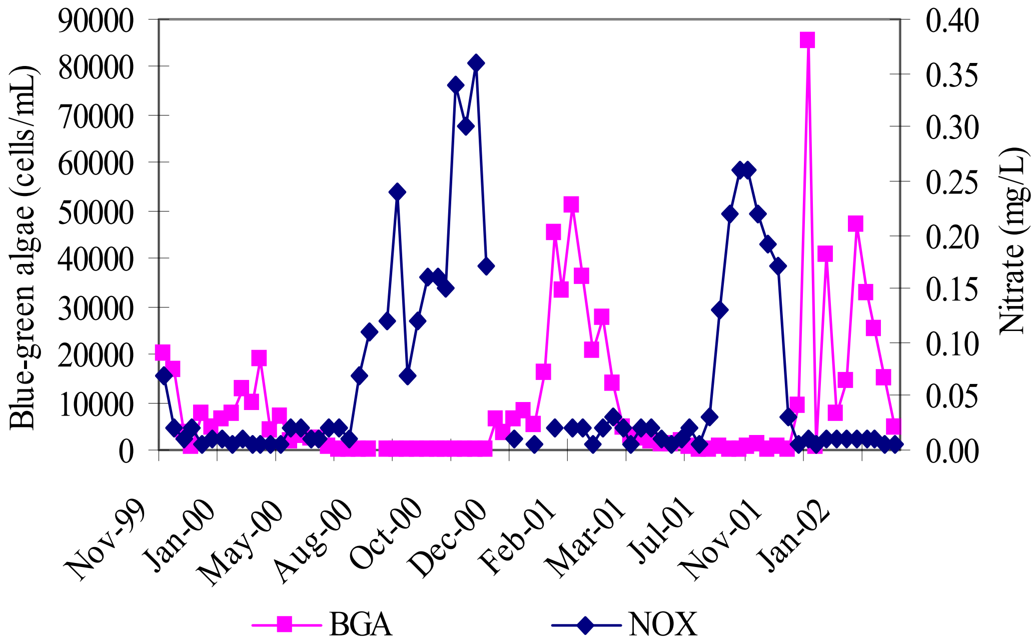


Figure 63. Nitrate and blue-green algal concentrations in Lake Cargelligo (site B), 1999 – 2002

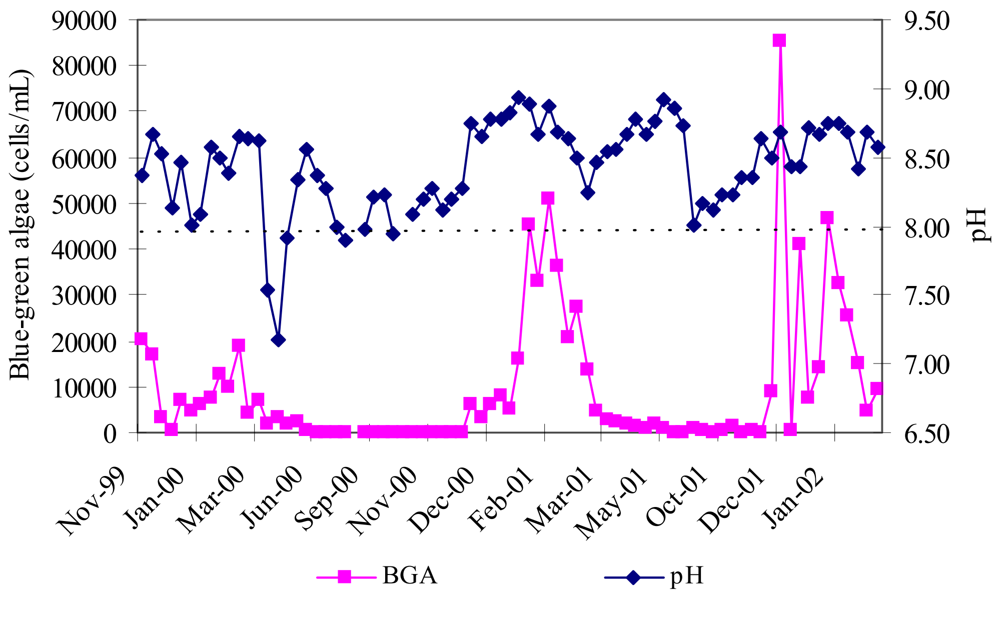


Figure 64. Blue-green algal numbers and pH levels at Lake Cargelligo site B (centre of lake), 1999 - 2002

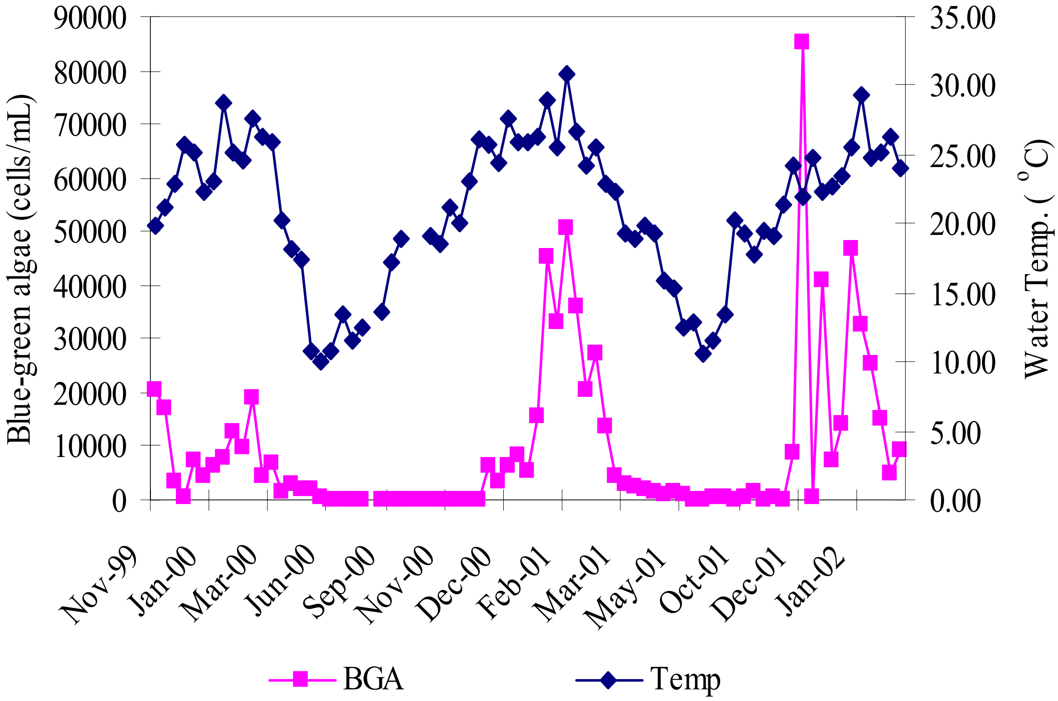


Figure 65. Blue-green algal numbers and water temperature at Lake Cargelligo site B (centre of lake), 1999 - 2002

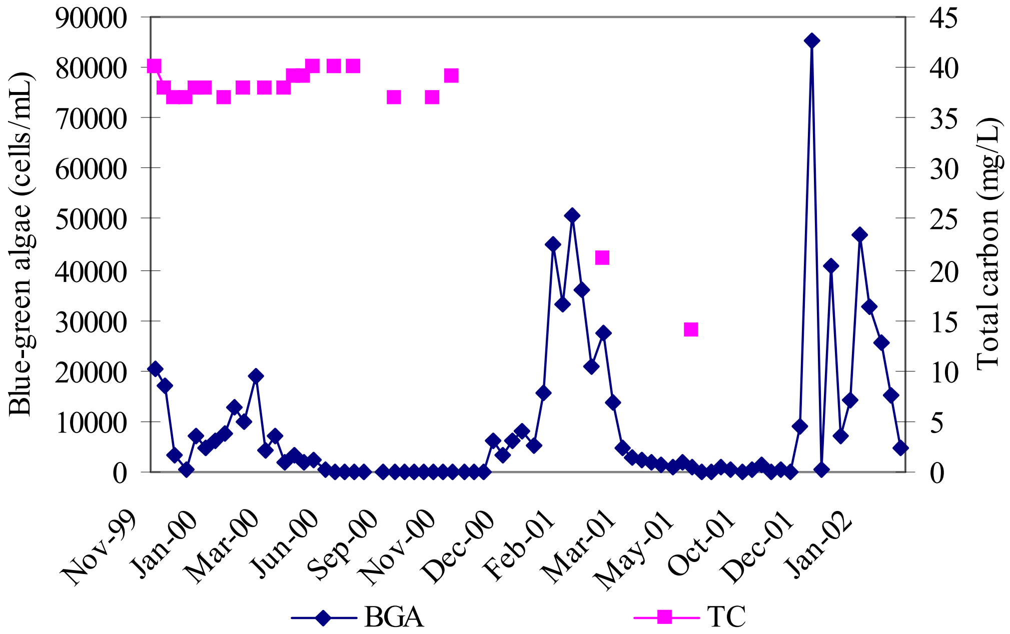


Figure 66. Total carbon and blue-green algal concentrations in Lake Cargelligo (site B), 1999 – 2002.

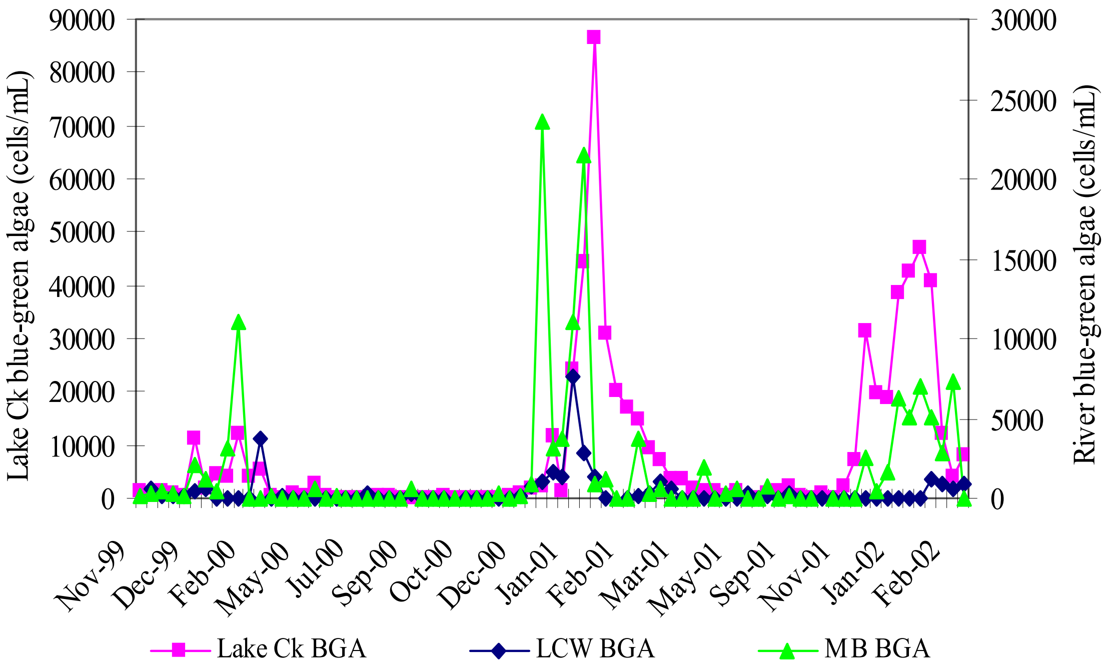


Figure 67. Blue-green algal concentrations in Lake Creek, Lake Cargelligo Weir and the Lachlan River at Murrin Bridge, 1999-2002. (note different scales on y axes)

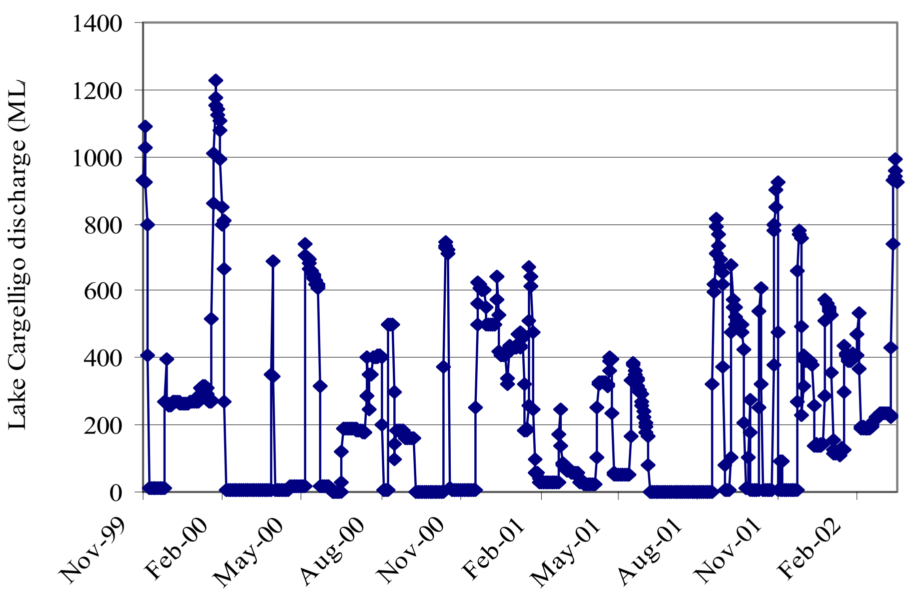


Figure 68. Lake Cargelligo discharge to the Lachlan River, 1999 - 2002

Blue-green algal concentrations were higher and more variable in Lake Brewster compared with Lake Brewster Weir (Figure 69, Appendix 1). The high mean blue-green algal counts in the Lake Brewster dead storage identify it as a possible source of algal blooms in the rest of the lake. The prevailing winds, which were from the south-east (see Section 3.3.3, Table 15), may have moved algae from the dead storage to the more northern section of the lake (see Figure 3). However, the high numbers may simply indicate more favourable growing conditions in that area of the lake then elsewhere (Figure 69). The causes of increased algal growth in the dead storage section of the lake may be related to a number of physical characteristics. These characteristics include reduced flow effects from the inlet and outlet, and less wave-action as the storage is deepest at this point and the prevailing winds travels from south to north (Figure 3). Average turbidity within the dead storage is about 20-25 NTU less than other sites in the lake, this would increase light penetration and availability for the algal population (Appendix 1). However, average nutrient concentrations are similar in the dead storage compared to the rest of the lake (Appendix 1).

Total nitrogen, total phosphorus and filterable reactive phosphorus all increased following the blue-green algal bloom of 2001 (Figures 70, 71 and 72). Algae, in particular phytoplankton, can increase total nutrients in the water column a number of ways. Fixation of atmospheric nitrogen by some species of blue-green algae may contribute significantly to the nitrogen influx in a water body under some conditions (Scheffer 1998). Nitrogen fixing species, such as *Anabaena*, were found in both Lake Cargelligo and Lake Brewster (Appendix 2). Increases in total phosphorus may be the result of the rapid mineralisation of settling phytoplankton at the sediment surface or high algal productivity stimulating the release of iron-bound phosphorus (Scheffer 1998). Also, high photosynthetic activity increases pH in the water column, which can promote the release of iron-bound phosphorus from sediment (Scheffer 1998). Total phosphorus increase may also be due to the storage of phosphorus within the algal cells, especially polyphosphate, and to other phosphorus compounds in the cells.

The increase of filterable reactive phosphorus remained at similar concentrations before and during the bloom (Figure 72). The recycling of soluble phosphorus would have been rapid during the bloom, with the uptake by algae of phosphorus as soon as it became available. The peak in filterable reactive phosphorus following the bloom may have been the result of the crash in the algal population and the decomposition of organic phosphorus (Figure 72).

As was the case in Lake Cargelligo, Lake Brewster frequently had pH levels above 8 (Figure 73). These high pH levels usually corresponded with high numbers of blue-green algae (Figure 73). As expected, there was a positive relationship between blue-green algae and water temperature, but this relationship did not appear as strong as that in Lake Cargelligo (Figure 74). There was also a dramatic decrease in total carbon levels in Lake Brewster during the 2001 algal bloom (Figure 75).

Figure 76 demonstrates how blue-green algae in outflows from Lake Brewster impacted on the Lachlan River immediately downstream. The magnitude of the impact is proportional to the amount of flow contributed from Lake Brewster (Figure 54). The Lake Brewster impact extended to weir pools much further downstream (Figure 77). The flow travel times from Willandra Weir to Hillston and Booligal Weirs are about 4 days and 12 days, respectively. This lag time is reflected in the blue-green algal numbers as they are transported downstream (Figure 77).

As shown in Figure 77 another impact of discharging lake water with high blue-green algal concentrations into the river is possible seeding of weir pools and lakes downstream. Discharge from Lake Cargelligo may be the primary source of blue-green algae in the Lachlan River. When plotting dissimilarity values there was some similarities between dominant taxa in Lake Cargelligo, Lake Brewster and Willandra Weir over two summers (Figures 78 and 79). However, there is little similarity in dominant taxa between Brewster Weir pool and the other three sites (Figures 78 and 79). Lakes Cargelligo and Brewster provide similar environments for blue-green algae and it is understandable that similar taxa would exist in both these lakes. Lake Brewster also appears to influence taxa in Willandra Weir to a greater degree than Brewster Weir (Figure 78 and 79). It also appears likely that Lake Cargelligo has little influence over blue-green taxa in Brewster Weir as flow, turbulence and other factors would alter community structure as the algae travel from Lake Cargelligo to Brewster Weir.

When comparing the dominant taxa from Lake Brewster dead storage and Lake Brewster site C for 1999/2000 there is a close relationship (Figures 80 and 81). Both sites were generally *Anabaena* dominated, with a switch to *Microcystis* January/February 2000. Willandra Weir follows a similar pattern to Lake Brewster site C with *Anabaena* domination at the beginning of the 1999/2000 summer, then switching to *Microcystis* in January 2000 (Figure 82). Algal populations in both Lake Brewster site C and Willandra Weir were *Anabaena* dominated throughout 2000/2001 (Figures 81 and 82). This supports previous conclusions that Lake Brewster is the primary source of blue-green algae to Willandra Weir and the Lachlan River downstream.

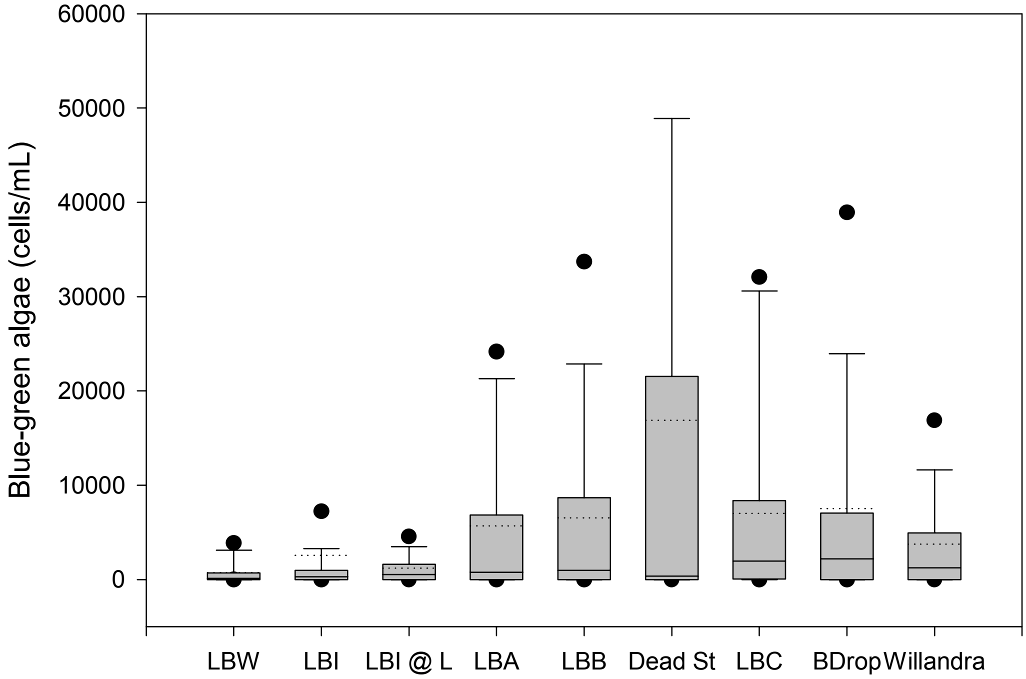


Figure 69. Blue-green algae concentrations at Lake Brewster sites, 1999 – 2002

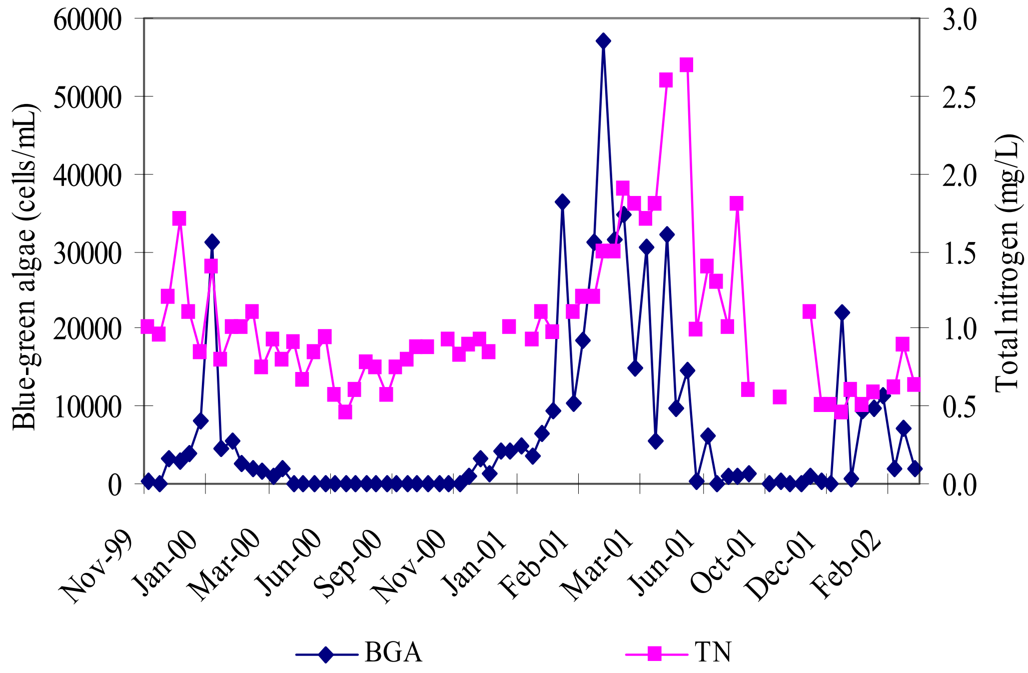


Figure 70. Lake Brewster site C total nitrogen and blue-green algal concentrations, 1999 – 2002.

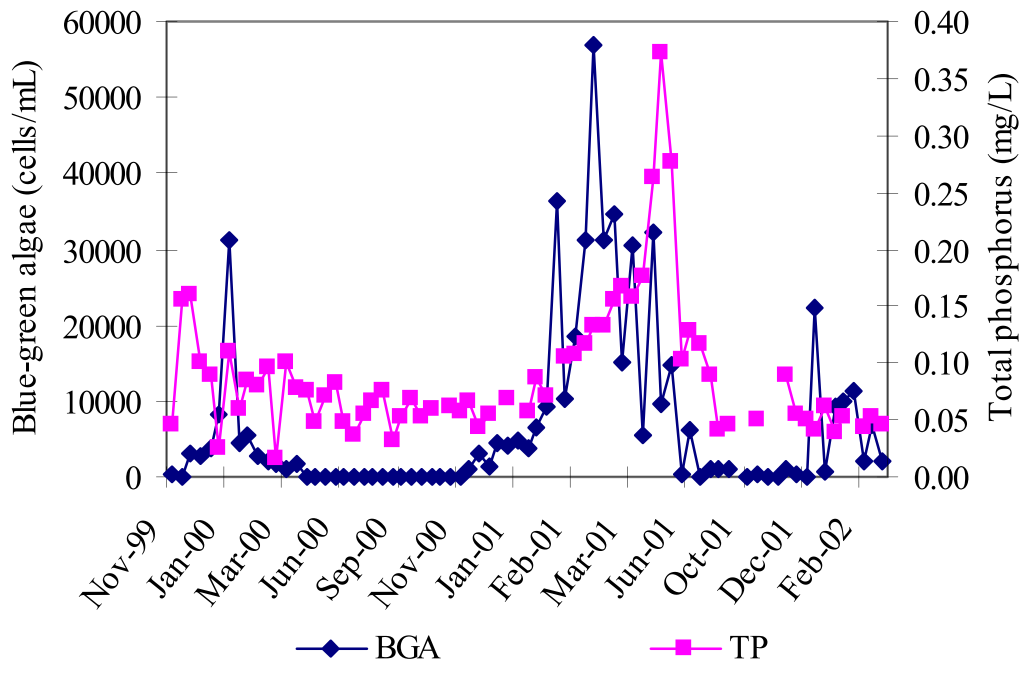


Figure 71. Lake Brewster site C total phosphorus and blue-green algal concentrations, 1999 – 2002.

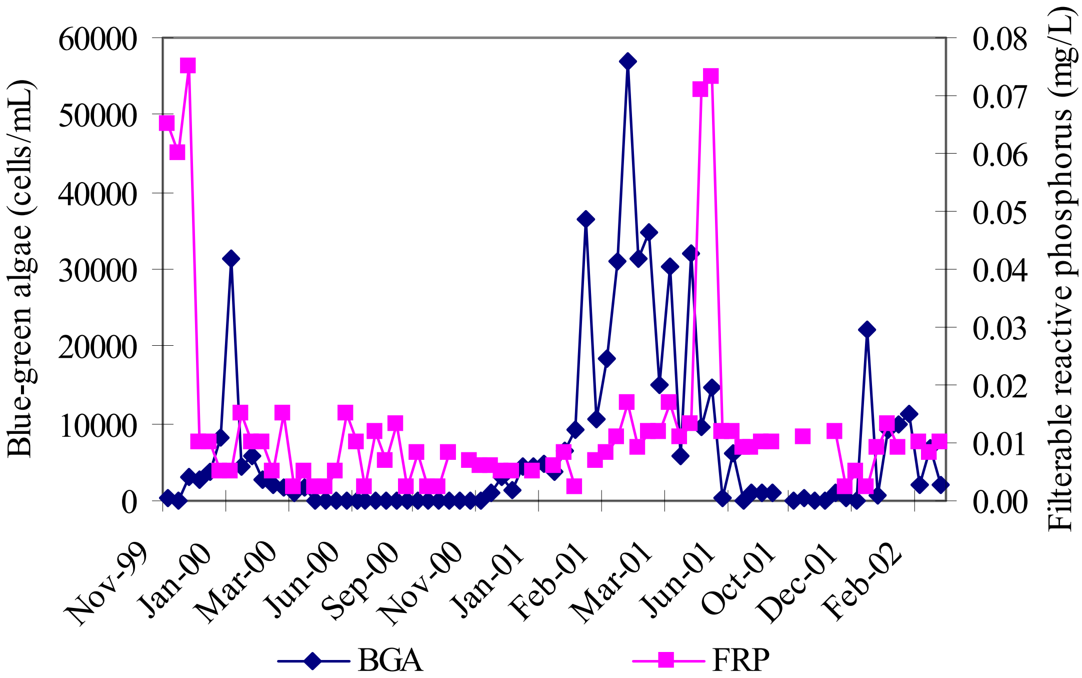


Figure 72. Lake Brewster site C filterable reactive phosphorus and blue-green algal concentrations, 1999 – 2002

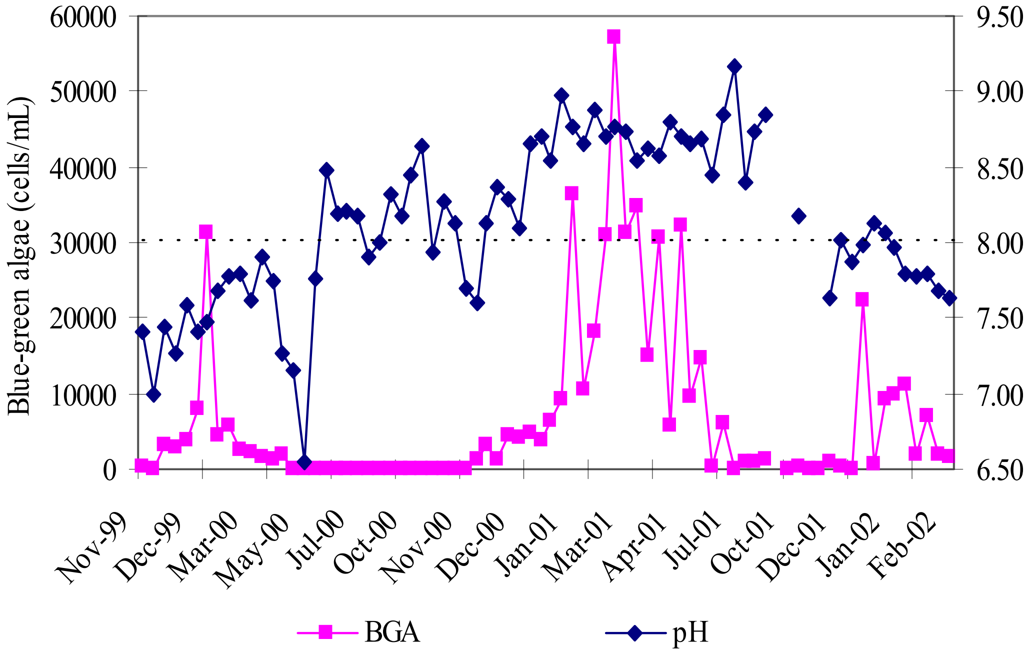


Figure 73 Blue-green algal numbers and pH levels at Lake Brewster site C (near storage gauge), 1999 - 2002

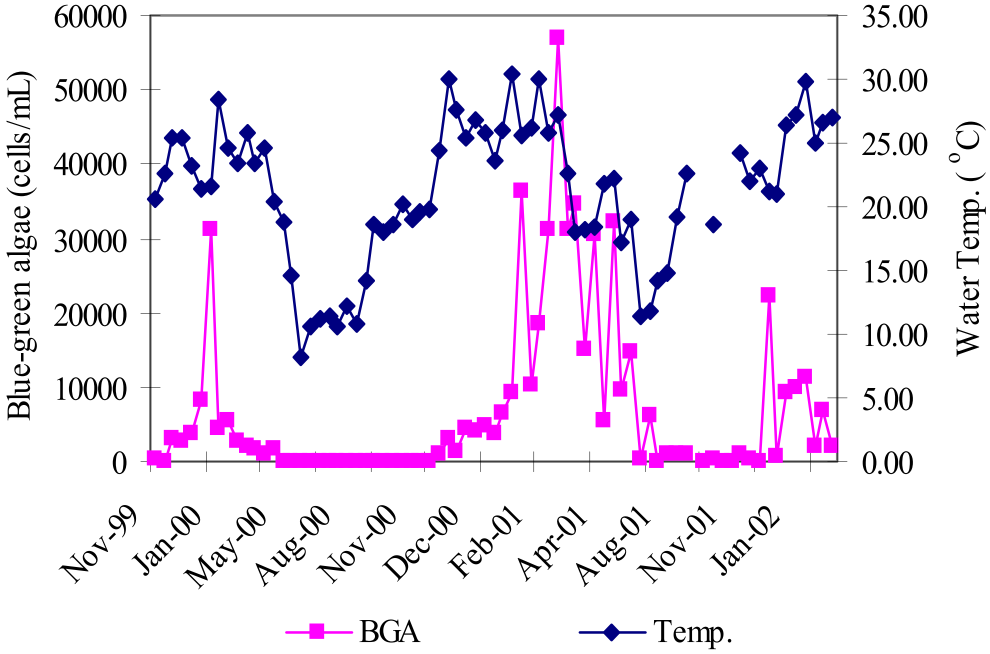


Figure 74. Blue-green algal numbers and water temperature at Lake Brewster site C (near storage gauge), 1999 - 2002

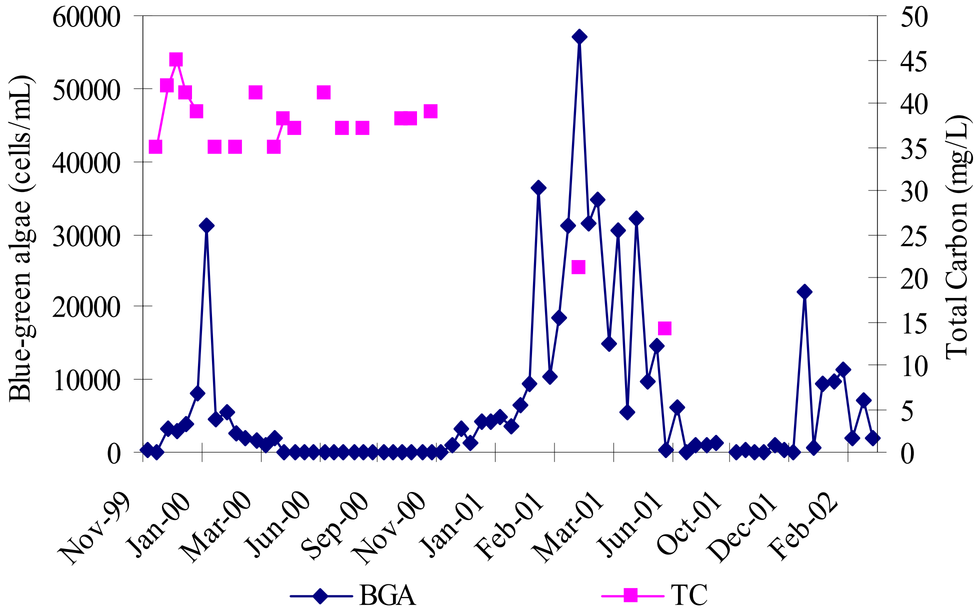


Figure 75. Total carbon and blue-green algal concentrations at Lake Brewster (site C), 1999 –2002

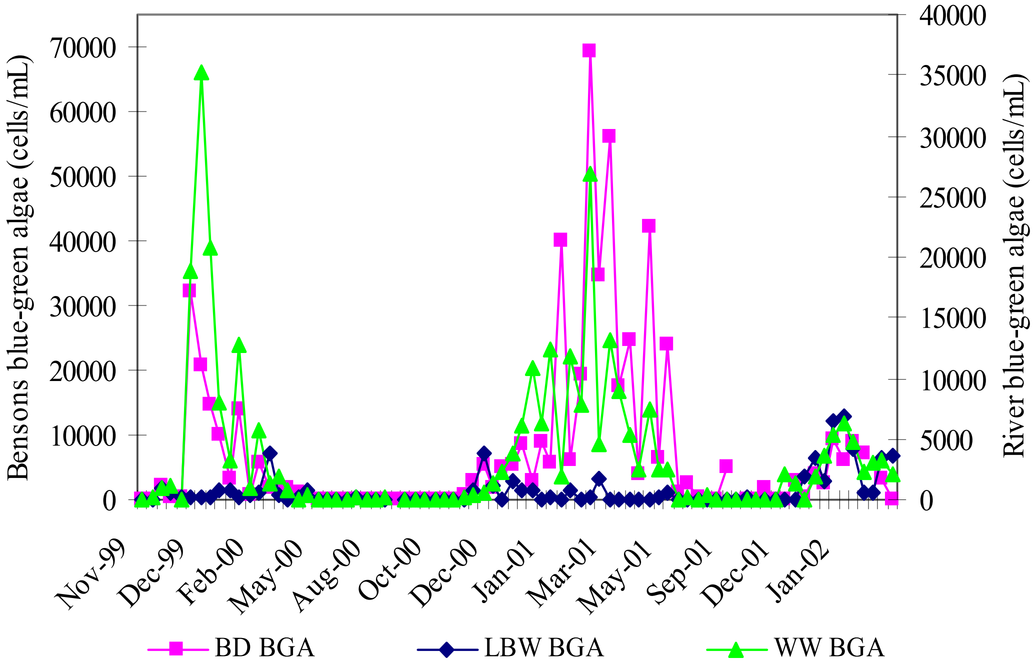


Figure 76. Blue-green algal concentrations at Bensons Drop Weir (Lake Brewster outlet), Lake Brewster Weir and Willandra Weir, 1999 – 2002

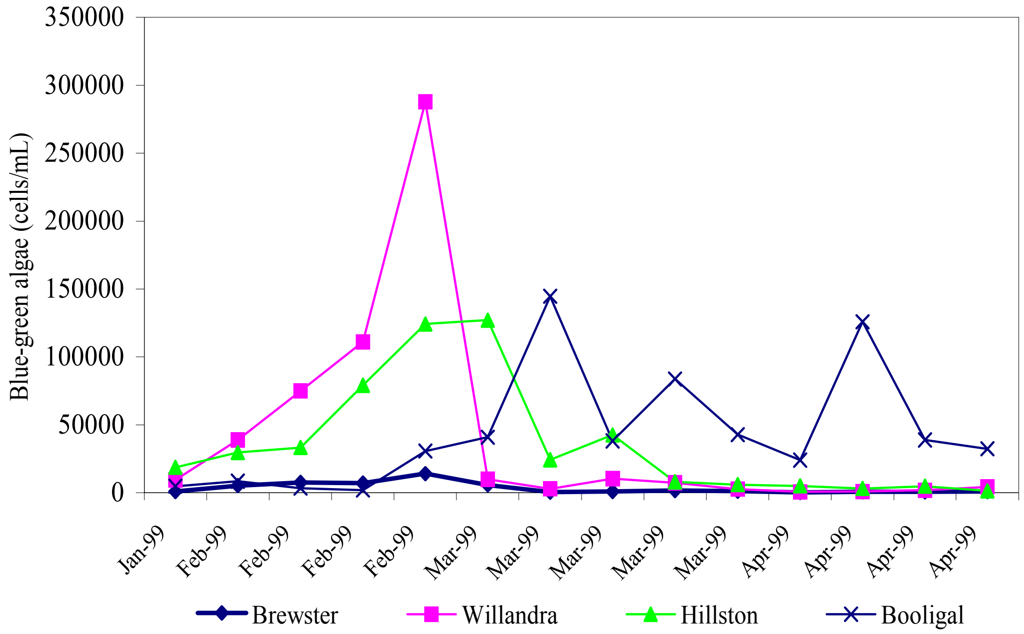


Figure 77. Blue-green algal concentrations in Lower Lachlan weir pools, January to April 1999 (note: Brewster refers to Lake Brewster Weir Pool)

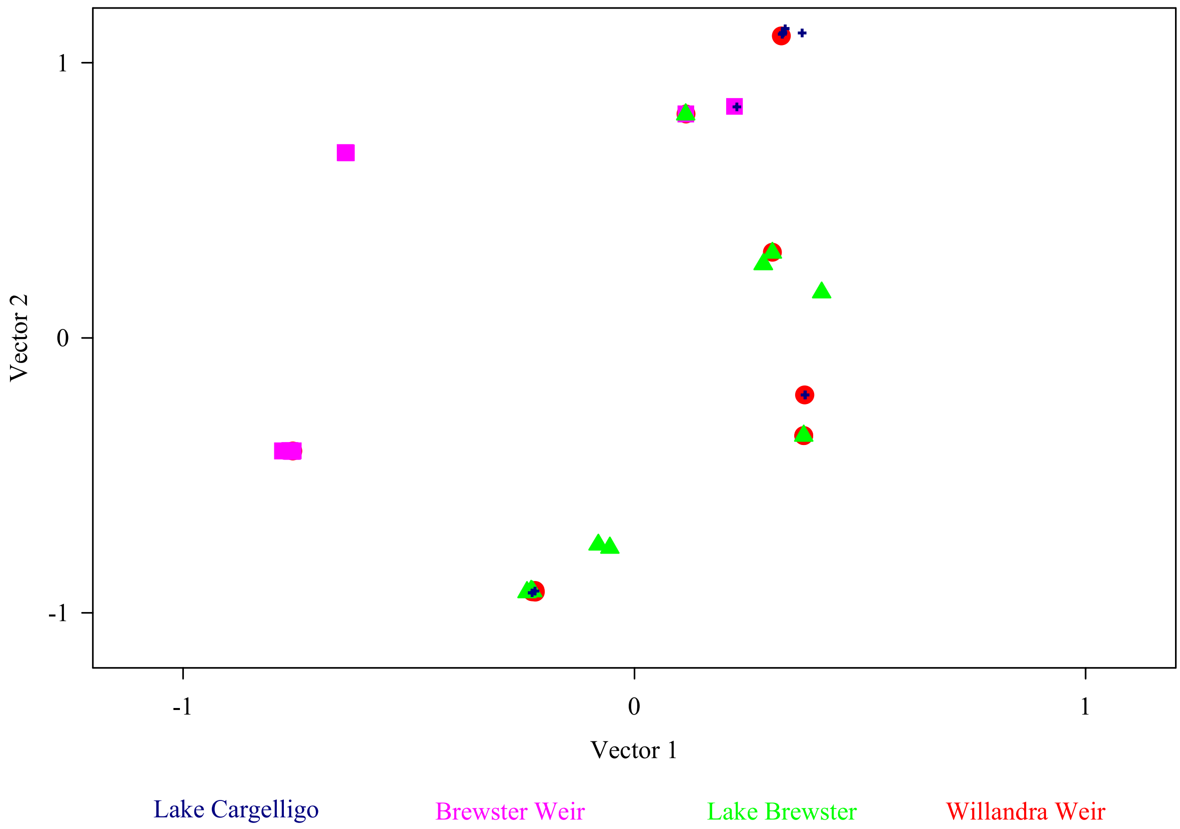


Figure 78. Dominant blue-green algae taxa in Lake Cargelligo, Brewster Weir, Lake Brewster and Willandra Weir, December 1999 – March 2000

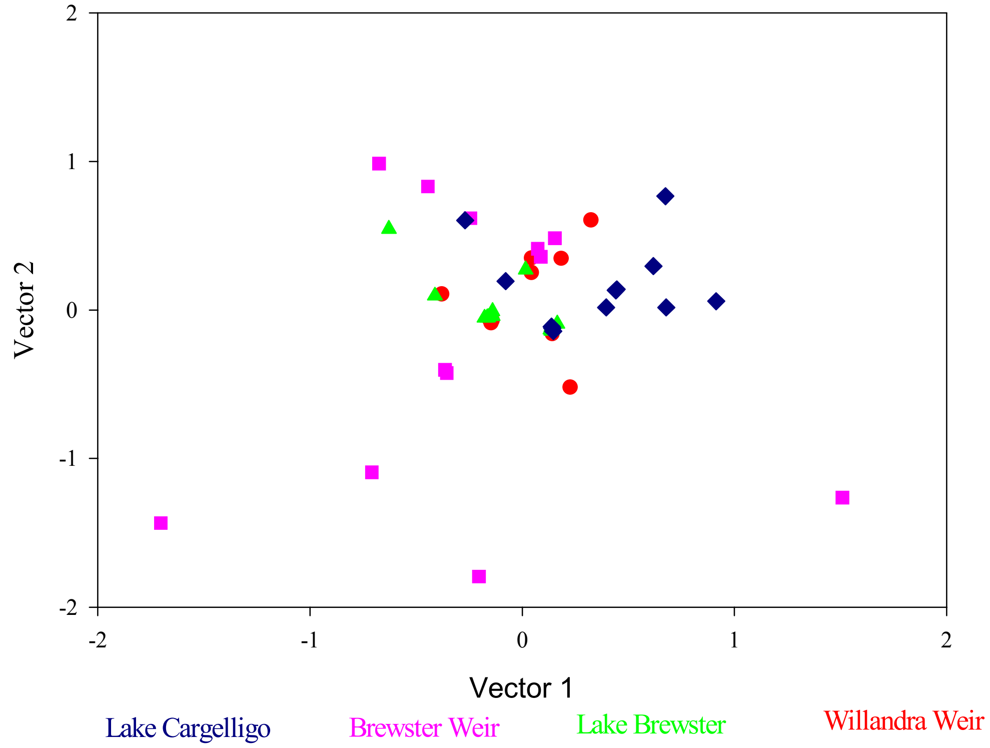


Figure 79. Dominant blue-green algae taxa in Lake Cargelligo, Brewster Weir, Lake Brewster and Willandra Weir, December 2000 – March 2001

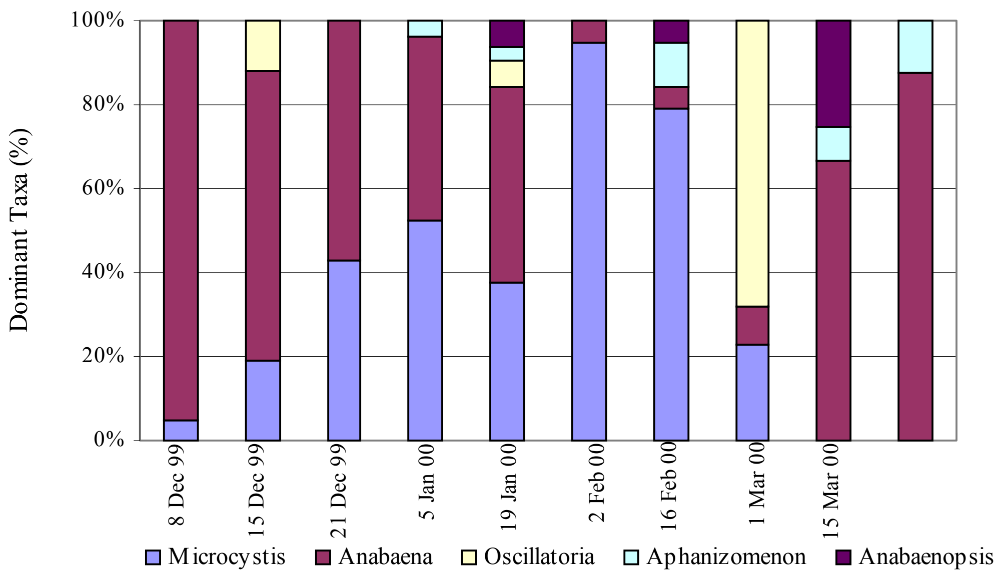


Figure 80. Dominant blue-green algal taxa in Lake Brewster Dead Storage, December 1999 – March 2000

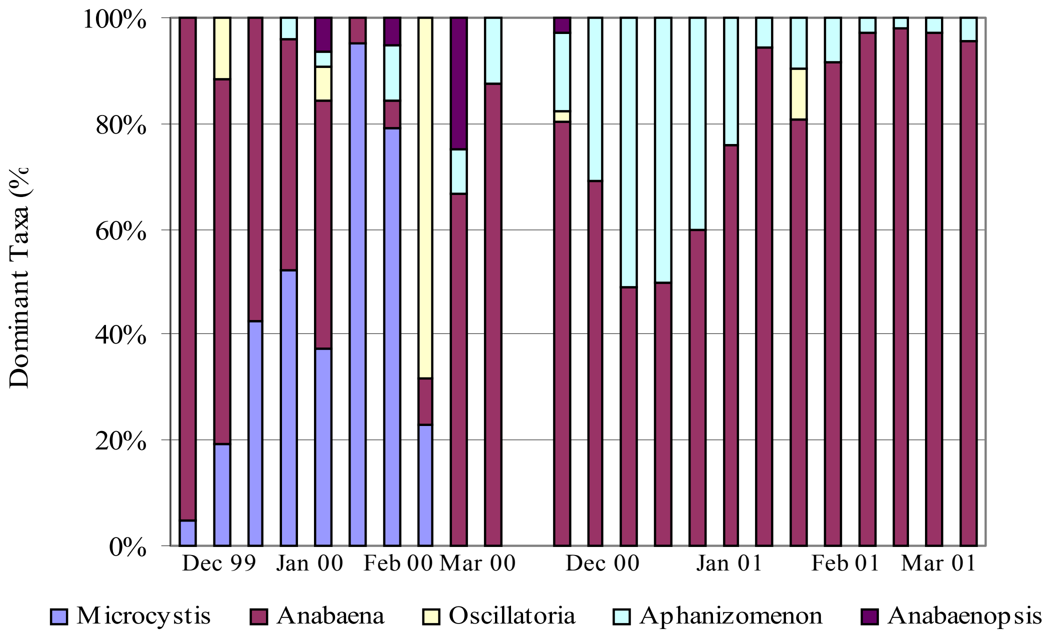


Figure 81. Dominant blue-green algal taxa in Lake Brewster site C, December 1999 – March 2000 and December 2000 – March 2001

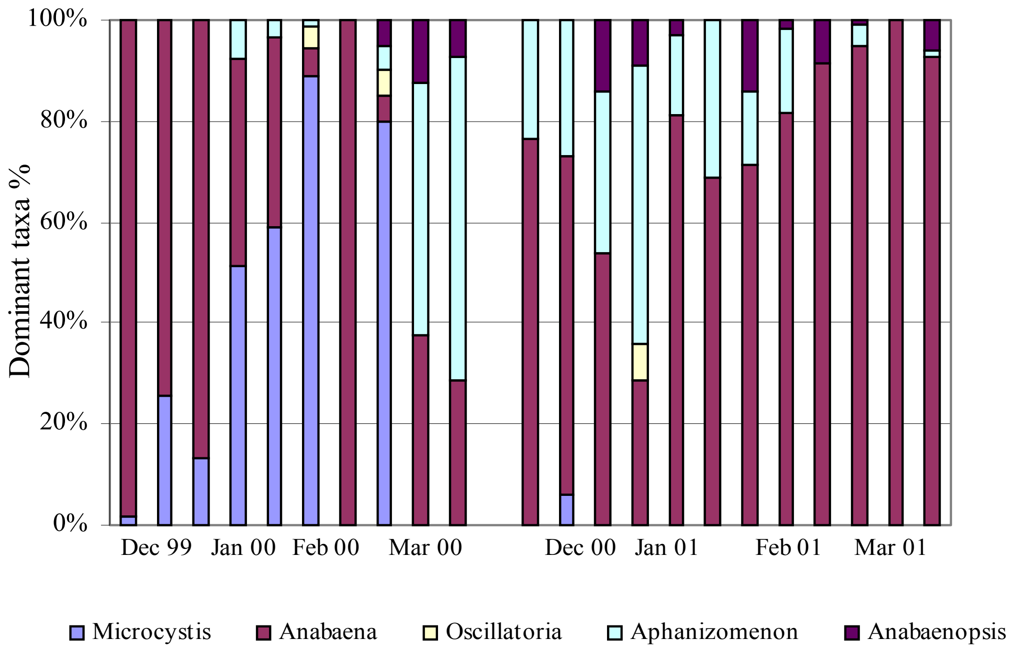


Figure 82. Dominant blue-green algal taxa in Willandra Weir, December 1999 – March 2000 and December 2000 – March 2001

3.5.2 Aquatic vegetation

Emergent and floating macrophyte species dominate aquatic plant communities in shallow, turbid lakes (Engel & Nichols 1994). Floating plants such as *Myriophyllum* avoid light limitation by concentrating their leaves just below the water surface. In comparison, emergent species such as *Typha* have photosynthetic adaptations similar to that of terrestrial plants.

Large stands of Cumbungi (*Typha Spp*), Ribbonweed (*Vallisneria gigantea*) and Milfoil (*Myriophyllum Spp*) were once present in Lake Cargelligo and Lake Brewster (Barry Orr, pers. comm., 2000). The noticeable loss of macrophytes from Lakes Brewster and Cargelligo began in 1974. An increase in turbidity and algal biomass corresponded with the loss of aquatic vegetation in both storages (Barry Orr, pers. comm., 2000) and most aquatic vegetation had disappeared from the storages by 1978 and failed to re-establish. However, Landsat imagery and personal observations indicate there are patches of Cumbungi which continue across both lakes, while Ribbonweed and Milfoil occur sporadically. Large temporary patches of both were observed in the northern shallow section of Lake Brewster in Spring 2001.

Many cases of lakes switching from a macrophyte dominated state with clear water to a turbid state with high concentrations of phytoplankton and suspended solids have been described (Scheffer 1998). This switch in states can be rapid and difficult to reverse due to a number of complex feedback mechanisms. One of the mechanisms involves increasing turbidity. As turbidity increases plant growth is usually inhibited, which can increase sediment resuspension and turbidity which, in turn, further reduces plant growth. For this reason lakes without aquatic macrophytes tend to stay that way. Alternatively vegetated systems tend to stay vegetated because the resulting water clarity promotes plant growth, the sediment is stable, the fish community are dominated by piscovores, and the overall vegetation productivity is high enough to sustain a large population of herbivores without collapsing (Scheffer 1998).

Factors thought to be responsible for the loss of macrophytes in the two storages include:

- increased nutrient loading leading to increased shading by phytoplankton and epiphyton;
- suspended sediments restricting light penetration, sediments may be from within the lakes or may arrive with Lachlan River inflows;
- bottom feeding fish such as Carp resuspend sediments, uproot vegetation and can cause physical damage to plants;
- frequent emptying of storages, especially Lake Brewster
- rising water levels reduce light availability, while low water levels cause damage to plants via wave action and desiccation, and
- Grazing and burning of macrophytes.

Re-establishment of macrophytes is thought to be a key component of improving water quality, particularly turbidity, within Lake Brewster storage. The current rapid draw-down and refilling of the storage does not adequately allow for plant establishment, growth and reproduction. Receding water exposes plants to desiccation, while rising water floods plants and limits photosynthesis. Investigations of other storages, such as Lake Mokoan in Victoria, indicate that restricting water level fluctuations to within 1.5 m per season has favourable affects on macrophyte growth and regeneration (Souter and Lewin 1999). Although this value is storage specific, further investigations should be undertaken to determine an appropriate water regime for Lake

Brewster. The duration of inundation and the rate of change in water level must allow plants to complete at least one flowering cycle to ensure propagation of the species for the following year.

Many studies confirm that the maximum depth inhibited by aquatic plants is positively correlated with water clarity (Scheffer 1998) and the depth to which light penetrates will limit plant growth. On average across all sites at Lake Brewster only 10.4% of the photosynthetically active radiation available at the surface penetrated to a depth of 0.5 m, of which only 2.4% extended down to 1 m depth and 0.17 % to 2 m (Table 16). The quality of available light may also change in turbid lakes, with most wavelengths rapidly absorbed and only red light remaining.

Light requirements of aquatic plants differ between species due largely to their differing growth forms and methods of propagation. However, it is generally accepted that rooted plants may colonise suitable substrate to a depth where light intensity is as low as 1-4% of the average intensity at the surface (Sculthorpe 1967). For the purposes of this study euphotic depth has been calculated as the depth to which light will penetrate above 1% of the surface irradiation (Scheffer 1998).

Table 16. Percentage light penetration (Photosynthetic Active Radiation) at Lake Brewster, 1999-2001.

	Depth of Light Measurement			
Lake Brewster	**0.5 M**	**1.0 M**	**1.5 M**	**2.0 M**
Site A	9.9 ± 7.8	2.0 ± 3.0	0.7 ± 2.7	0.1 ± 0.1
Site B	9.6 ± 7.4	2.1 ± 2.7	0.5 ± 1.1	0.0 ± 1.0
Site C	11.7 ± 8.2	3.2 ± 3.3	0.8 ± 1.0	0.4 ± 0.8

When the lakebed is within the euphotic zone, photosynthesis is possible, therefore to promote macrophyte re-establishment within the storage the euphotic depth may need to be increased via water quality improvements or water depth reduced to facilitate light penetration. The euphotic zone reached the bottom of Lake Brewster at site C on only five sampling occasions during 1999 to 2001 (Figure 83). This suggests large areas of the lake bottom were often devoid of sufficient light for photosynthesis (Figure 83), possibly hindering macrophyte growth. However, Figure 84 demonstrates that during extended periods of inundation and relatively calm weather, such as occurred in the months of June and July 2000 (see Table 15, Section 3.3.3.2), the average euphotic depth may reach extensive areas of the lake bottom. Figure 84 also demonstrates that lowering water levels will also increase the submerged area the euphotic zone reaches. However, as has been shown in Section 3.2, lowering water depth also increases turbidity which inturn will reduce light penetration.

Further factors hindering the re-establishment of aquatic macrophytes in Lake Brewster include:

- lake bed drying out after seasonal emptying;
- disturbance by waves and carp causes physical damage as well as reduced light penetration;
- loose sediments facilitate uprooting by birds, carp and other fish;
- lakebed grazing has a substantial impact on the type and quality of vegetation in and around lakes (Clarke et al 1997), and
- lakebed cropping and stubble burning are thought to significantly impact upon macrophyte seed bank.

A potential area for macrophyte re-establishment lies in the northern section of the storage contained between the inlet and outlet channels (Figure 3). This area, when inundated is large and shallow, wave action is severe at its perimeter but is lessened on the interior due to block banks around the outlet channel. Large stands of *Myriophyllum* have been observed in these areas. Maintaining the storage at depth reduces the impact of wave action upon the lakebed sediments and allows macrophyte establishment in this northern section, and was seen in the spring of 2001.

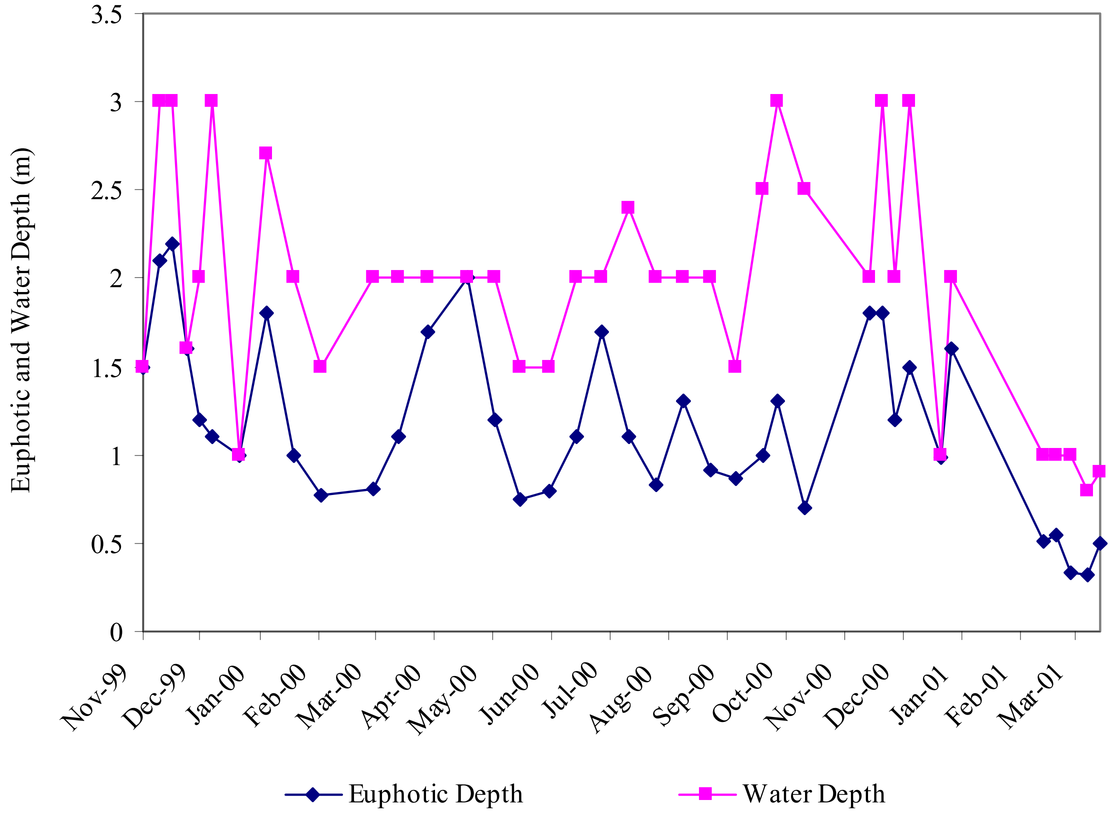


Figure 83. Euphotic depth and water depth at Lake Brewster site C, 1999 – 2001

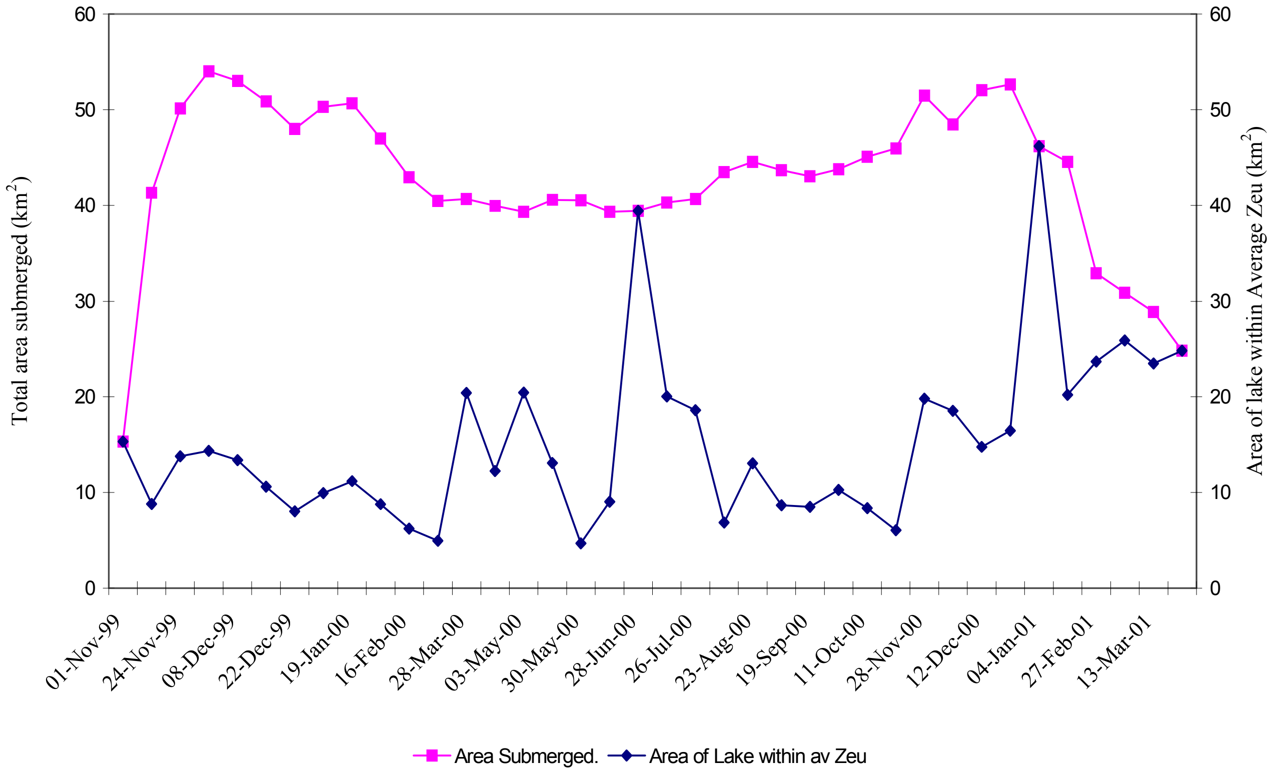


Figure 84. Area of Lake Brewster submerged and within average euphotic zone depth , 1999 -2001.

CHAPTER 4

CONCLUSION

Both Lake Cargelligo and Lake Brewster impacted on water quality in the Lower Lachlan River. The extent and magnitude of the impact depended on the volume of water released in relation to the volume of water already in the river, the time of year and the physical, chemical and biological characteristics of the lakes at the time of the release. Generally, it can be said Lake Cargelligo had a lesser impact as a result of its smaller discharge, but when discharges did occur, electrical conductivity and blue-green algal concentrations increased immediately downstream. Lake Brewster had a greater impact on the river due to larger release volumes that lead to increased electrical conductivity, turbidity, nutrients and blue-green algae in the Lachlan River downstream.

The release of water from Lake Cargelligo appeared to increase the salt concentrations in the Lachlan River. Electrical conductivity in the Lachlan River immediately downstream of Lake Cargelligo was higher when compared to upstream of the outlet. Evaporation losses from Curlew Water, Sheet of Water and Lake Cargelligo resulted in increasing concentrations of salt in each water body. Though electrical conductivity remained reasonably constant in Lake Cargelligo, the impact on the river depended on the quantity of the lake discharge, existing flow in the river and the electrical conductivity in the receiving water.

Electrical conductivity in Lake Brewster was higher than that measured in the Lachlan River and the Lake Brewster inlet on the majority of sampling occasions. The impact of this on the Lachlan River depended on Lake Brewster storage level, the proportion of discharge from the storage to total flow downstream and the electrical conductivity of the receiving water.

For most of the sampling period Willandra Weir had higher average electrical conductivity levels than Lake Brewster Weir and the Lachlan River downstream of Lake Brewster Weir. From this we may conclude that Lake Brewster discharge caused increased salt concentrations in the Lower Lachlan River, provided all other possible sources of salt have been eliminated.

As the storage was drained and inflows ceased, isolation from fresh inputs of river water allowed the salt levels in Lake Brewster to increase. This increase in electrical conductivity was most likely a result of evaporation. The magnitude of the downstream impact of these higher salt concentrations was reduced because of operational difficulties in draining the lake. However, recent work on the outlet channel may enable better drainage at these lower water levels and could lead to significant dramatic electrical conductivity increases in the river downstream if water quality is not monitored prior to and during discharge.

Increasing turbidity and suspended sediment loads in Lake Brewster are a major concern for the management of the Lower Lachlan River and the lake itself. The movement of water through the lake caused increases in turbidity and subsequent releases from Lake Brewster increased turbidity of the receiving river water.

Wind driven resuspension appeared to be a major cause of the high suspended solid concentrations in Lake Brewster. The storage is long and shallow and is located in a very open, unprotected part of the catchment. The predominant wind direction is from the south east, running the length of the storage at an average velocity of 2.97 m/s. Winds of this speed have the capacity to generate large waves. The fine and very colloidal lake bed is easily resuspended by wave action, settling rates are slow and the lake becomes increasingly turbid.

The average total suspended solids load released from Lake Brewster each month (measured at Bensons Drop Weir) varied according to lake height, release volume and turbidity of the storage. There appeared to be an overall increase in suspended solid loads leaving the storage when compared to that entering the storage.

Nutrient concentrations in Lake Brewster were found to increase with the concentration of suspended sediments. Nutrients accumulate in lake bed sediments as a result of the settlement of dissolved and particulate nutrients. With the disruption of sediments by wind induced wave action, sediments are resuspended, thus re-introducing nutrients into the water column. Nutrient release to the water column can also arise as a result of sediment resuspension events (Halliwell and O'Shanassy 1997).

The high level of nutrients in both lakes was not only a function of internal inputs from the resuspension of the substrate, but also external sources such as nutrient rich inflows. Both storages have been filled from upstream flooding on the rising arm of the flood hydrograph. Nutrient concentrations are usually greatest during the first stages of a flood event (Cullen *et al.* 1978). Avoidance of the first pulse may reduce the contribution of external nutrient loads.

The existence of large phytoplankton populations in both lakes also influenced nutrient concentrations and dynamics within the storages. Some blue-green algae can fix atmospheric nitrogen and contribute to the influx of nitrogen to a lake (Scheffer 1998). However, probably the greatest impact of phytoplankton on nutrients occurs when settling algae mineralise at the sediment surface which may release phosphorus into the water column (Scheffer 1998). Phytoplankton thrive in nutrient-rich environments but also may sustain high nutrient concentrations within water bodies.

Both Lake Cargelligo and Lake Brewster develop blue-green algal blooms during most summers. Nutrients did not appear to be a limiting factor for algal growth in either lake, with both lakes exceeding recommended nutrient trigger values for the protection of modified aquatic ecosystems. Other variables such as water temperature, pH and wind conditions appear to have a greater influence on the growth of blue-green algal populations in the lakes. In the case of Lake Cargelligo blooms may also be seeded from the two small storages along the inlet channel, Sheet of Water and Curlew Water. These two water bodies are wind protected and blooms have been observed on both storages before blooms are detected in Lake Cargelligo.

The impact of Lake Cargelligo on the Lachlan River blue-green algal population appeared to be fairly minimal. This may be the result of DSNR's Lakes Cargelligo and Brewster algal warning and storage operating protocol (Appendix 3), which requires the dilution or discontinuation of water release from Lake Cargelligo or Brewster when a large bloom is detected. Discharges also met with a well-mixed, flowing river that would not be conducive for maintaining an algal bloom. The river does not enter another weir situation until it reaches Brewster Weir pool, some 90 km downstream.

There was a clear relationship between blue-green algal numbers and taxa composition in Lake Brewster and Willandra Weir. Though numbers in Willandra Weir have been kept in check to some degree through the dilution of outflows and the introduction of the algal warning system (Appendix 3). The presence of large blue-green populations negatively impacts on overall outflow water quality by increasing turbidity and odour. As well, it may be toxic. It also reduces operating options in the Lower Lachlan. If blue-green algal numbers become too high in the storage and/or Willandra Weir, discharge from Lake Brewster is discontinued (Appendix 3). This means that almost all water must be delivered from Wyangala Dam, some 3 weeks away in water travel time. This also results in the mid-Lachlan River being kept higher than what would be preferable.

4.2 Recommendations

The reduction of the impact Lake Cargelligo and Lake Brewster have on river electrical conductivity concentrations could be achieved in a number of ways. These include:

- Ensuring that Lake Cargelligo and Lake Brewster discharges, which generally have higher salt concentrations, are adequately diluted by river water. This would require monitoring electrical conductivity of the discharge of both Lake Cargelligo and Lake Brewster and the receiving river water to ensure that appropriate dilutions are occurring.
- Reducing residence time of water in Lake Cargelligo storage through flushing. Regular flushing of Lake Cargelligo could reduce the effects of evaporation within the storage. However, care would need to be taken to ensure flushing the lake does not adversely impact on the river in other ways. This measure is less appropriate for Lake Brewster as little mixing occurs between inlet water and resident dead storage water.

The reduction of turbidity in Lake Brewster would have the added benefit of reducing nutrient concentrations within the water column. Improved water quality will not only benefit the lake but the Lachlan River downstream.

Turbidity can be reduced by:

- Macrophyte re-establishment through maintaining the storage at levels more favourable for macrophyte growth and protection of bottom sediments. Also replanting appropriate macrophytes and protection from grazing. Protection from grazing should also be considered for the inlet and outlet channels.
- Creation of a wetland area in the shallow northern area of the lake adjacent to the outflow channel. This would filter suspended solids and reduce wave action.
- Dilute turbid releases with less turbid Lake Brewster Weir water.
- Investigate wind and wave reduction techniques. Macrophytes are one way of reducing the impact of wind and wave action on sediments, but engineering options may also offer some solutions. These options may include creating cells within the storage to reduce the fetch and re-positioning the inlet and outlet channels.

Exposure and desiccation of littoral sediments during the summer have the potential to influence the long-term phosphorus balance of Lake Brewster. The rapid refilling of the storage results in an accelerated release of phosphorus from the sediments and this is made worse by the onset of anoxic conditions due to decaying organic matter. The recommended management options to reduce sediment phosphorus release include:

- Prevent or minimise sediment desiccation by maintaining the storage at as high a level as possible. This includes a reduction of drawdown in summer to minimise sediment drying and prevent increased phosphorus release. The pressure upon Lake Brewster to supply water to downstream irrigators over the summer period makes this option difficult to achieve.
- Phosphorus flushing as described by De Groot & Van Wijck (1993), involves a process where phosphorus is repeatedly flushed from sediments with the ultimate aim to reduce phosphorus levels in the sediment and thus reduce internal loading. This process would involve repeatedly drying and rapidly filling the storage to increase sediment phosphorus release. The process is likely to have initial

undesirable effects such as an increased incidence of algal blooms as well as seeding the Lower Lachlan with increased concentrations of nutrients and algae.

- Lakebed cropping and export harvesting may be another effective way to export nutrients from lakebed sediments. However this option may increase turbidity in the lake by mechanical disturbance of the lake bed. It would also reduce the success of re-establishing macrophytes and the lake would need to remain dry for extended periods.
- The re-establishment of macrophytes would help utilise sediment phosphorus and make nutrients less available to phytoplankton. It would also reduce the extent of anoxic conditions in the lake following reflooding as macrophytes would not decay as terrestrial vegetation does.

As algal blooms are frequently driven by nutrient availability, it has been recommended in previous reports to divert nutrient rich floodwaters (usually first flush) away from the lakes (Bowling 1994). The rehabilitation of Lake Cargelligo and Lake Brewster may require the formulation of a water management strategy that would not only assist in the return of macrophytes but would also investigate the possibility of reducing the nutrient load introduced to the lakes through inflows.

To reduce blue-green algal blooms in Lake Cargelligo, options include:

- Taking Sheet of Water off-line to reduce the residence time of inlet water spent in a shallow, turbid water body. Reducing the number of shallow water bodies inflows pass through may lower blue-green algal concentrations. By-passing Sheet of Water would improve water delivery efficiency and have the added benefit of reducing the turbidity and algal populations of the intake water before it reaches the lake. Another simple engineering option is to use screens to prevent algal and associated scum from leaving the lake.
- Reducing nutrient inputs from the river by avoiding the rising arm of flood pulses. This would reduce nutrient loading within the lake over time.
- Frequent flushing of the lake as water temperatures warm. It has been found that flushing the lake system before blue-green algal populations are too large helps reduce the numbers, water movement is crucial to keeping blue-green algal numbers in-check. However this may result in an overall deterioration of receiving water through an increase in nutrients and turbidity.
- Reintroducing aquatic macrophytes through replanting and carp removal. Macrophytes would compete for nutrients and improve the overall lake environment as an aquatic habitat.
- Improving the Lakes Cargelligo and Brewster algal warning and storage operating protocol through better monitoring and water management.

Recommendations for reducing blue-green algal populations in Lake Brewster include:

- Reducing nutrient inputs from the river by avoiding the rising arm of flood pulses. As recommended for Lake Cargelligo.
- Reintroducing aquatic macrophytes through replanting and carp removal. This was also an option for turbidity and nutrient reduction. Recommendations for reducing turbidity and nutrients would also help reduce blue-green algal concentrations and re-establish macrophytes.
- Engineering solutions could include the relocation of the outlet channel to avoid wind blown blue-green algal populations. The present location of the outlet channel results in the prevailing winds concentrating phytoplankton populations near the outlet regulator. Also, as suggested for Lake Cargelligo, is to use screens to prevent algal and associated scum from leaving the lake.

- As recommended for Lake Cargelligo, improve the Lakes Cargelligo and Brewster algal warning and storage operating protocol through better monitoring and water management.

The preferred approach to implementing this report is to first assess the costs and benefits of these recommendations, and to then prioritise them.

The process of rehabilitation of the lakes must be seen in the long-term as it will take a number of years before improvements within the lakes will be seen. However, some strategies, such as improved water management, will have immediate benefits to the Lower Lachlan River.

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SUMMARY STATISTICS FOR LACHLAN LOWER LAKES WATER QUALITY INVESTIGATION

Site 412011 – Lachlan River at Lake Cargelligo Weir

Parameter	Units	Number	Minimum	Average	Maximum	Standard Deviation	Median
Water Temperature	^oC	78	10	21.14	30.6	5.78	21.7
Dissolved Oxygen	mg/L	78	3.96	7.68	11.47	1.59	7.49
EC	µs/cm	79	304.6	423.33	781.2	110.83	388
pH	pH	79	6.87	7.62	8.28	0.28	7.63
Turbidity	NTU	79	15.7	44.07	133	20.90	38.6
SS	mg/L	72	2.5	35.26	178	29.57	25.5
SPO_4	mg/L	73	0.0025	0.0130	0.045	0.0071	0.011
NO_X	mg/L	73	0.005	0.0524	0.46	0.0777	0.02
TN	mg/L	73	0.3	0.6026	1.3	0.1676	0.59
TP	mg/L	73	0.025	0.0570	0.137	0.0192	0.055
Blue-Green Algae	Cells/mL	77	0	386.51	7655	1049.67	0
Other Algae	Cells/mL	77	645	6133.34	21736	4328.47	4859

Site 412101 – Lake Cargelligo Inlet

Parameter	Units	Number	Minimum	Average	Maximum	Standard Deviation	Median
Water Temperature	^oC	78	2.47	20.95	29.5	5.98	22.41
Dissolved Oxygen	mg/L	78	3.84	7.50	11.16	1.79	7.195
EC	µs/cm	79	307.7	420.87	769.9	109.48	389
pH	pH	79	6.92	7.61	8.45	0.29	7.58
Turbidity	NTU	79	11.9	44.82	146	21.17	41.2
SS	mg/L	69	7	33.78	151	21.98	29
SPO_4	mg/L	69	0.0025	0.0137	0.035	0.0071	0.012
NO_X	mg/L	69	0.005	0.0425	0.25	0.0600	0.01
TN	mg/L	69	0.31	0.5720	1.05	0.1435	0.55
TP	mg/L	69	0.015	0.0569	0.143	0.0229	0.055
Blue-Green Algae	Cells/mL	79	0	615.86	13663	2182.05	0
Other Algae	Cells/mL	79	752	5914.66	24277	4451.99	4514

Site 41210145 – Lake Cargelligo Intake DS Sheet of Water

Parameter	Units	Number	Minimum	Average	Maximum	Standard Deviation	Median
Water Temperature	^{o}C	79	9.5	21.55	30	5.51	22.26
Dissolved Oxygen	mg/L	78	0.05	8.50	13.92	1.82	8.325
EC	µs/cm	79	233	415.00	848.6	95.11	399
pH	pH	79	6.92	8.00	9.48	0.54	7.99
Turbidity	NTU	79	17	61.16	200	33.16	51.8
SS	mg/L	69	9	38.23	100	19.56	35
SPO_4	mg/L	69	0.0025	0.0102	0.036	0.0064	0.01
NO_X	mg/L	69	0.005	0.0225	0.17	0.0314	0.01
TN	mg/L	69	0.27	0.7268	3.6	0.4802	0.6
TP	mg/L	68	0.025	0.0671	0.263	0.0394	0.06
Blue-Green Algae	Cells/mL	77	0	11733.69	406151	48312.45	564
Other Algae	Cells/mL	77	821	7503.87	26537	5248.29	5835

Site 41210155 – Lake Cargelligo Intake DS Curlew Water

Parameter	Units	Number	Minimum	Average	Maximum	Standard Deviation	Median
Water Temperature	^{o}C	79	11.2	21.74	30.76	5.29	22.9
Dissolved Oxygen	mg/L	78	4.68	8.55	13.28	1.51	8.405
EC	µs/cm	79	319	421.24	705	77.41	402
pH	pH	79	6.89	7.99	9.35	0.54	8.02
Turbidity	NTU	79	12	40.46	104	17.87	36.1
SS	mg/L	75	2.5	20.57	62	11.82	18
SPO_4	mg/L	75	0.0025	0.0085	0.028	0.0048	0.008
NO_X	mg/L	75	0.005	0.0275	0.23	0.0380	0.02
TN	mg/L	75	0.35	0.7000	1.8	0.2543	0.63
TP	mg/L	75	0.015	0.0507	0.091	0.0158	0.05
Blue-Green Algae	Cells/mL	79	0	17714.77	400101	58108.64	1127
Other Algae	Cells/mL	79	225	7832.56	60129	8706.26	5566

Site 41210156 – Lake Cargelligo Site A (Inlet)

Parameter	Units	Number	Minimum	Average	Maximum	Standard Deviation	Median
Water Temperature	^{o}C	78	10.3	21.21	29.35	5.20	22.015
Dissolved Oxygen	mg/L	78	5.73	9.08	14.08	1.62	8.92
EC	µs/cm	78	327.9	466.01	641.2	64.03	467.55
pH	pH	78	7.28	8.34	9.23	0.39	8.325
Turbidity	NTU	78	16.2	44.13	85.5	15.80	41.2
SS	mg/L	72	2.5	28.81	65	12.95	26.5
SPO_4	mg/L	71	0.0025	0.0074	0.031	0.0048	0.007
NO_X	mg/L	72	0.005	0.0367	0.26	0.0547	0.02
TN	mg/L	72	0.35	0.7915	1.4	0.1947	0.77
TP	mg/L	72	0.011	0.0569	0.15	0.0195	0.057
Blue-Green Algae	Cells/mL	79	0	13525.97	194144	29863.89	2255
Other Algae	Cells/mL	79	127	10708.41	62671	10833.28	7551
Tot. Carbon	mg/L	21	10	33.59	39	6.88	36
Tot. Organic C	mg/L	21	5.3	7.61	9.7	0.98	7.6

Site 41210045 – Lake Cargelligo Site B (Centre of Lake)

Parameter	Units	Number	Minimum	Average	Maximum	Standard Deviation	Median
Water Temperature	^{o}C	75	10.06	21.13	30.87	5.21	22.24
Dissolved Oxygen	mg/L	75	5.54	9.02	12.64	1.26	8.97
EC	µs/cm	75	471.1	541.93	619.9	27.87	543.7
pH	pH	75	7.18	8.44	8.94	0.33	8.5
Turbidity	NTU	75	5.1	30.41	81.9	16.18	28.5
SS	mg/L	68	2.5	17.37	52	11.33	16
SPO_4	mg/L	68	0.0025	0.0062	0.019	0.0035	0.005
NO_X	mg/L	68	0.005	0.0621	0.36	0.0925	0.02
TN	mg/L	68	0.55	0.8307	1.2	0.1553	0.84
TP	mg/L	68	0.015	0.0443	0.092	0.0153	0.044
Blue-Green Algae	Cells/mL	75	0	9509.77	85204	15235.69	3100
Other Algae	Cells/mL	75	519	9641.13	73398	12280.48	6484
Tot. Carbon	mg/L	20	14	36.25	40	6.60	38
Tot. Organic C	mg/L	20	6.8	7.51	8.9	0.59	7.4

Site 41210157 – Lake Cargelligo Site C (Outlet)

Parameter	Units	Number	Minimum	Average	Maximum	Standard Deviation	Median
Water Temperature	^{o}C	76	9.87	21.15	30.27	5.24	22.175
Dissolved Oxygen	mg/L	76	5.83	9.10	12.33	1.48	8.915
EC	µs/cm	76	426.3	523.21	598.9	39.11	527.25
pH	pH	76	7.22	8.46	9.11	0.35	8.5
Turbidity	NTU	76	9.3	46.19	170.7	25.02	40.65
SS	mg/L	68	8	34.19	85	18.35	31
SPO_4	mg/L	69	0.0025	0.0074	0.022	0.0047	0.006
NO_X	mg/L	68	0.005	0.0470	0.34	0.0697	0.02
TN	mg/L	69	0.5	0.8690	1.3	0.1797	0.85
TP	mg/L	68	0.02	0.0559	0.107	0.0196	0.0535
Blue-Green Algae	Cells/mL	73	0	12440.22	112961	20865.25	2818
Other Algae	Cells/mL	73	414	12434.58	119976	16156.49	9351
Tot. Carbon	mg/L	20	15	35.98	40	6.40	38
Tot. Organic C	mg/L	20	5.6	7.75	11	1.14	7.35

Site 412008 – Lake Creek (Lake Cargelligo Outlet)

Parameter	Units	Number	Minimum	Average	Maximum	Standard Deviation	Median
Water Temperature	^{o}C	77	9.7	21.40	31.1	5.63	22.21
Dissolved Oxygen	mg/L	78	4.29	7.87	11.51	1.61	7.78
EC	µs/cm	79	326	550.20	912	75.38	555.9
pH	pH	79	7.02	8.02	8.98	0.49	8.01
Turbidity	NTU	79	17.6	70.14	170	26.48	69.2
SS	mg/L	72	2.5	61.52	370	46.87	51.5
SPO_4	mg/L	71	0.0025	0.0091	0.045	0.0074	0.007
NO_X	mg/L	71	0.005	0.0361	0.16	0.0378	0.02
TN	mg/L	72	0.55	0.9581	1.4	0.2108	0.945
TP	mg/L	72	0.01	0.0758	0.159	0.0263	0.07
Blue-Green Algae	Cells/mL	79	0	8068.70	86636	14681.53	1465
Other Algae	Cells/mL	79	1024	11766.51	65176	10605.86	8457

Site 41210067 – Lachlan River at Murrin Bridge

Parameter	Units	Number	Minimum	Average	Maximum	Standard Deviation	Median
Water Temperature	^oC	78	9.8	21.16	30.2	5.69	22.275
Dissolved Oxygen	mg/L	77	4.78	8.73	72.27	7.51	7.43
EC	µs/cm	79	316	445.76	856.8	101.27	434
pH	pH	79	6.89	7.72	8.64	0.35	7.75
Turbidity	NTU	79	24.6	54.51	165	21.88	50.6
SS	mg/L	63	5	47.44	230	32.63	42
SPO_4	mg/L	63	0.0025	0.0123	0.05	0.0087	0.01
NO_X	mg/L	63	0.005	0.0528	0.24	0.0615	0.02
TN	mg/L	63	0.36	0.6514	1	0.1664	0.65
TP	mg/L	63	0.01	0.0554	0.115	0.0178	0.053
Blue-Green Algae	Cells/mL	79	0	1701.10	23651	4093.07	141
Other Algae	Cells/mL	79	563	6444.05	42345	5801.91	4846

Site 41210161 - Lachlan River DS Lake Cargelligo Weir

Parameter	Units	Number	Minimum	Average	Maximum	Standard Deviation	Median
Water Temperature	^oC	64	9.80	20.70	29.6	5.89	21.475
Dissolved Oxygen	mg/L	64	4.46	7.99	11.41	1.65	7.71
EC	µs/cm	65	306.20	423.14	817.6	112.70	396.2
pH	pH	65	6.97	7.63	8.18	0.28	7.64
Turbidity	NTU	65	14.20	44.69	133	19.08	42.8
SS	mg/L	64	10	37.09	154	27.34	30
SPO_4	mg/L	64	0.00	0.0126	0.045	0.0070	0.011
NO_X	mg/L	64	0.01	0.0489	0.26	0.0623	0.02
TN	mg/L	63	0.21	0.5625	0.98	0.1583	0.54
TP	mg/L	63	0.02	0.0548	0.124	0.0181	0.051
Blue-Green Algae	Cells/mL	66	0.00	155.08	3388	518.78	0
Other Algae	Cells/mL	66	818.00	5277.85	16527	3927.70	4037.5

Site 412048 –Lachlan River at Lake Brewster Weir

Parameter	Units	Number	Minimum	Average	Maximum	Standard Deviation	Median
Water Temperature	^oC	79	10.6	21.98	32.8	5.94	22.77
Dissolved Oxygen	mg/L	78	4.58	7.83	11.35	1.60	7.875
EC	µs/cm	79	284	443.86	646.2	82.65	434
pH	pH	77	6.86	7.69	8.88	0.36	7.7
Turbidity	NTU	79	7.22	38.95	136	20.18	35.1
SS	mg/L	69	2.5	26.92	140	23.28	20
SPO_4	mg/L	70	0.0025	0.0107	0.04	0.0071	0.01
NO_X	mg/L	70	0.005	0.0402	0.18	0.0526	0.01
TN	mg/L	70	0.39	0.6183	0.86	0.1172	0.62
TP	mg/L	70	0.029	0.0514	0.11	0.0152	0.05
Blue-Green Algae	Cells/mL	77	0	726.06	6776	1409.03	113
Other Algae	Cells/mL	77	1070	6527.65	19868	3652.37	5605

Site 412102 – Lake Brewster Intake

Parameter	Units	Number	Minimum	Average	Maximum	Standard Deviation	Median
Water Temperature	^oC	79	10.7	21.46	31.3	5.50	22.15
Dissolved Oxygen	mg/L	78	3.79	7.89	11.44	1.70	7.46
EC	µs/cm	79	254.8	443.83	649	80.62	434.1
pH	pH	79	6.73	7.73	8.46	0.39	7.77
Turbidity	NTU	79	17.2	43.55	124	19.69	39.2
SS	mg/L	71	2.5	28.99	77	16.07	25
SPO_4	mg/L	71	0.0025	0.0101	0.03	0.0058	0.01
NO_X	mg/L	71	0.005	0.0375	0.18	0.0462	0.02
TN	mg/L	71	0.38	0.6786	1.5	0.1931	0.66
TP	mg/L	71	0.027	0.0568	0.12	0.0179	0.052
Blue-Green Algae	Cells/mL	79	0	2574.47	119634	13494.32	282
Other Algae	Cells/mL	79	744	9231.48	74244	10247.91	7205

Site 41210158 – Lake Brewster Intake at Lake

Parameter	Units	Number	Minimum	Average	Maximum	Standard Deviation	Median
Water Temperature	^{o}C	79	8.3	21.19	31.37	5.65	22.11
Dissolved Oxygen	mg/L	78	5.43	8.42	12	1.65	8.04
EC	µs/cm	79	245	450.92	649.6	83.34	436
pH	pH	79	6.74	7.98	8.96	0.48	8
Turbidity	NTU	79	16.7	66.01	197.2	35.46	54.2
SS	mg/L	73	2.5	49.42	142	30.63	40
SPO_4	mg/L	73	0.0025	0.0111	0.04	0.0065	0.01
NO_X	mg/L	73	0.005	0.0333	0.19	0.0465	0.02
TN	mg/L	73	0.4	0.8130	2.4	0.3220	0.74
TP	mg/L	73	0.03	0.0747	0.154	0.0289	0.069
Blue-Green Algae	Cells/mL	78	0	1205.63	9598	1747.61	550.5
Other Algae	Cells/mL	78	538	12493.47	71436	12817.27	8010

Site 41210159 – Lake Brewster Site A (Inlet)

Parameter	Units	Number	Minimum	Average	Maximum	Standard Deviation	Median
Water Temperature	^{o}C	59	8.64	20.03	30.49	5.92	20.33
Dissolved Oxygen	mg/L	58	6.67	9.06	12.04	1.39	8.975
EC	µs/cm	59	322	515.41	786.9	92.52	506
pH	pH	59	6.26	8.17	9.35	0.61	8.24
Turbidity	NTU	59	26.7	94.08	673	86.10	76.4
SS	mg/L	58	2.5	53.04	170	39.40	37
SPO_4	mg/L	57	0.0025	0.0094	0.035	0.0063	0.007
NO_X	mg/L	58	0.005	0.0333	0.18	0.0342	0.02
TN	mg/L	58	0.34	0.9798	2.1	0.4034	0.85
TP	mg/L	58	0.024	0.0808	0.313	0.0512	0.0695
Blue-Green Algae	Cells/mL	57	0	5682.21	43191	9818.73	789
Other Algae	Cells/mL	57	987	29214.25	166840	32178.26	18459
Tot. Carbon	mg/L	19	11	34.22	41	6.85	36
Tot. Organic C	mg/L	18	5.4	8.52	10	1.49	8.95

Site 41210160 – Lake Brewster Site B (Centre of Lake)

Parameter	Units	Number	Minimum	Average	Maximum	Standard Deviation	Median
Water Temperature	^oC	57	8.69	20.22	30.54	5.85	21.25
Dissolved Oxygen	mg/L	56	7.04	9.10	12.4	1.29	8.71
EC	µs/cm	57	321	529.55	793.7	108.52	506
pH	pH	57	6.26	8.21	9.11	0.63	8.34
Turbidity	NTU	57	18	85.29	210	45.24	76.2
SS	mg/L	56	2.5	49.82	200	40.77	35
SPO_4	mg/L	55	0.0025	0.0123	0.086	0.0158	0.009
NO_X	mg/L	56	0.005	0.0281	0.12	0.0233	0.02
TN	mg/L	56	0.52	1.0693	2.7	0.4784	0.885
TP	mg/L	56	0.029	0.0928	0.43	0.0741	0.066
Blue-Green Algae	Cells/mL	55	0	6536.76	46580	11006.40	987
Other Algae	Cells/mL	55	724	37892.38	544848	74574.55	23250
Tot. Carbon	mg/L	19	20	35.37	40	5.46	38
Tot. Organic C	mg/L	19	7.2	9.45	14	1.45	9.4

Site 412108 – Lake Brewster Site C (Outlet)

Parameter	Units	Number	Minimum	Average	Maximum	Standard Deviation	Median
Water Temperature	^oC	74	8.21	21.20	30.49	5.39	22.185
Dissolved Oxygen	mg/L	72	3.06	8.62	12.42	1.84	8.24
EC	µs/cm	74	353.8	508.94	767.3	96.72	494.05
pH	pH	74	6.54	8.12	9.17	0.54	8.13
Turbidity	NTU	74	3.29	85.23	274	55.89	75.9
SS	mg/L	66	2.5	70.95	310	61.13	56
SPO_4	mg/L	66	0.0025	0.0129	0.075	0.0166	0.009
NO_X	mg/L	66	0.005	0.0224	0.07	0.0138	0.02
TN	mg/L	65	0.45	1.0212	2.7	0.4631	0.92
TP	mg/L	66	0.015	0.0888	0.373	0.0611	0.0695
Blue-Green Algae	Cells/mL	72	0	7106.67	57025	11468.06	1976
Other Algae	Cells/mL	72	2184	22834.00	228945	30766.61	13186.5
Tot. Carbon	mg/L	19	14	36.21	45	7.22	38
Tot. Organic C	mg/L	19	5.2	9.17	13	2.17	8.8

Site 41210163 – Lake Brewster Dead Storage

Parameter	Units	Number	Minimum	Average	Maximum	Standard Deviation	Median
Water Temperature	^oC	26	10.24	21.24	32.18	6.23	22.135
Dissolved Oxygen	mg/L	26	5.68	9.14	11.37	1.48	8.98
EC	µs/cm	26	458	529.26	624	48.47	519.65
PH	pH	26	8.2	8.56	9.13	0.27	8.52
Turbidity	NTU	26	19.6	67.50	154.5	34.37	64.25
SS	mg/L	26	2.5	31.48	73	21.14	24.5
SPO_4	mg/L	26	0.0025	0.0080	0.035	0.0071	0.006
NO_X	mg/L	26	0.005	0.0208	0.04	0.0088	0.02
TN	mg/L	26	0.57	0.9950	2	0.4271	0.815
TP	mg/L	26	0.03	0.0735	0.178	0.0404	0.0605
Blue-Green Algae	Cells/mL	26	0	18215.04	120138	28969.56	2213
Other Algae	Cells/mL	26	9635	47102.12	226404	44928.84	33212.5
Tot. Carbon	mg/L	5	21	34.00	39	7.42	37
Tot. Organic C	mg/L	5	7.8	9.14	10	0.93	9.2

Site 41210081 – Lake Brewster Outlet below storage gauge

Parameter	Units	Number	Minimum	Average	Maximum	Standard Deviation	Median
Water Temperature	^oC	56	10.59	20.84	29.8	5.84	21.655
Dissolved Oxygen	mg/L	56	6.12	8.77	11.45	1.50	8.765
EC	µs/cm	56	350.1	521.32	727.8	102.85	510.2
PH	pH	56	6.97	8.10	9.13	0.50	8.055
Turbidity	NTU	55	20.5	97.37	378	67.05	87.5
SS	mg/L	50	7	89.18	470	72.82	77.5
SPO_4	mg/L	50	0.0025	0.0118	0.051	0.0105	0.009
NO_X	mg/L	50	0.005	0.0262	0.1	0.0156	0.02
TN	mg/L	50	0.45	1.0796	2.5	0.5126	0.935
TP	mg/L	50	0.035	0.0946	0.325	0.0648	0.0685
Blue-Green Algae	Cells/mL	54	0	10219.80	125819	19402.63	1924.5
Other Algae	Cells/mL	54	1648	21801.63	90619	21534.22	13740.5

Site 412047 – Benson's Drop Weir

Parameter	Units	Number	Minimum	Average	Maximum	Standard Deviation	Median
Water Temperature	°C	75	2.4	21.07	30.1	6.02	22.2
Dissolved Oxygen	mg/L	74	5.8	8.74	12.01	1.45	8.785
EC	µs/cm	75	354.9	515.60	776.9	99.55	505
pH	pH	74	7.1	8.13	8.83	0.44	8.18
Turbidity	NTU	75	7.08	105.63	1000	116.55	81.4
SS	mg/L	67	5	78.82	210	48.81	71
SPO_4	mg/L	67	0.0025	0.0125	0.12	0.0164	0.01
NO_X	mg/L	67	0.005	0.0277	0.08	0.0171	0.02
TN	mg/L	67	0.43	1.0706	2.6	0.5263	0.95
TP	mg/L	67	0.026	0.0898	0.29	0.0519	0.075
Blue-Green Algae	Cells/mL	74	0	7518.38	69112	13298.78	2214.5
Other Algae	Cells/mL	74	0	22046.51	167759	24013.73	14163.5

Site 412038 – Lachlan River at Willandra Weir

Parameter	Units	Number	Minimum	Average	Maximum	Standard Deviation	Median
Water Temperature	°C	79	9.5	21.06	29.13	5.60	22.43
Dissolved Oxygen	mg/L	77	4.64	7.74	10.97	1.60	7.72
EC	µs/cm	79	320	468.89	645.6	71.60	473
pH	pH	79	6.92	7.78	8.71	0.39	7.82
Turbidity	NTU	78	24.5	51.44	115	17.73	49.6
SS	mg/L	70	2.5	37.59	80	16.06	37.5
SPO_4	mg/L	70	0.0025	0.0102	0.045	0.0066	0.01
NO_X	mg/L	70	0.005	0.0331	0.18	0.0347	0.02
TN	mg/L	70	0.43	0.7953	1.6	0.2556	0.775
TP	mg/L	70	0.031	0.0639	0.127	0.0218	0.061
Blue-Green Algae	Cells/mL	77	0	3757.53	35225	6315.67	1253
Other Algae	Cells/mL	77	1111	15434.01	218231	25565.82	8845

41210162 – Lachlan River DS Lake Brewster Weir

Parameter	Units	Number	Minimum	Average	Maximum	Standard Deviation	Median
Water Temperature	°C	63	10.46	21.27	29.1	5.80	22.98
Dissolved Oxygen	mg/L	63	4.62	8.06	12.82	1.72	7.6
EC	µs/cm	63	351	452.60	649.2	79.60	432
pH	pH	63	6.87	7.64	8.13	0.28	7.64
Turbidity	NTU	62	11.2	34.58	101.9	15.81	32.1
SS	mg/L	61	7	26.51	78	13.63	23
SPO_4	mg/L	61	0.0025	0.0106	0.03	0.0054	0.01
NO_X	mg/L	61	0.005	0.0303	0.19	0.0394	0.02
TN	mg/L	61	0.29	0.6477	1.4	0.1723	0.63
TP	mg/L	61	0.033	0.0546	0.103	0.0165	0.051
Blue-Green Algae	Cells/mL	62	0	1101.10	13604	2416.19	141
Other Algae	Cells/mL	62	2113	7470.73	19234	4618.36	6398

A P P E N D I X 2

ALGAL TAXA OF THE LACHLAN LOWER LAKES AND THE LOWER LACHLAN RIVER

Phylum/Sub-Phylum	Genus
Cyanobacteria	Anabaena
	Anabaenopsis
	Aphanizomenon
	Aphanocapsa
	Arthrospira
	Chroococcus
	Coelosphaerium
	Cylindrospermopsis
	Cylindrospermum
	Dactylococcopsis
	Limnothrix
	Lyngbya
	Merismopedia
	Microcystis
	Oscillatoria
	Phormidium
	Planktolynbya
	Planktothrix
	Pseudanabaena
	Raphidiopsis
	Snowella
Chlorophyta	Actinastrum
	Ankistrodesmus
	Ankyra
	Botryococcus
	Bracteacoccus
	Carteria
	Characium
	Chlamydomonas
	Chlorella
	Chlorogonium
	Chodatella
	Closteriopsis
	Closterium
	Coelastrum
	Cosmarium
	Crucigenia
	Dicellula
	Dictyosphaerium
	Didymocystis
	Dimorphococcus
	Elakatothrix

	Eudorina
	Gloeoactinium
	Gloeocystis
	Golenkinia
	Gonium
	Kirchneriella
	Micractinium
	Micrasterias
	Monoraphidium
	Mougeotia
	Nephrocytium
	Oocytis
	Ourococcus
	Pandorina
	Pediastrum
	Planktonema
	Pseudococcomyxa
	Pteromonas
	Quadrigula
	Scenedesmus
	Schroederia
	Selenastrum
	Sphaecrocystis
	Spirogyra
	Spondylosium
	Staurastrum
	Staurosira
	Stichococcus
	Tetraedron
	Tetrastrum
	Treubaria
	Ulothrix
	Uronema
	Wislouchiella
	Xanthidium
Euglenaphyta	Euglena
	Lepocinclis
	Phacus
	Strombomonas
	Trachelomonas
Cryptophyta	Chroomonas
	Cryptomonas
	Rhodomonas
Dinophyta	Ceratium
	Gymnodinium
	Peridinium
Chrysophyta	Acanthochloris
	Centritractus
	Diceras
	Dinobryon
	Mallomonas

	Pseudotetraedron
	Synura
Chloromonadophyta	Merotrichia
Bacillariophyta	Acanthoceras
	Achnanthidium
	Amphora
	Asterionella
	Aulacoseira
	Bacillaria
	Ceratoneis
	Chaetoceros
	Cocconeis
	Coscinodiscus
	Crysosigma
	Cyclotella
	Cymbella
	Diatoma
	Encyonema
	Epithemia
	Eunotia
	Fragilaria
	Frustulia
	Gomphonema
	Gyrosigma
	Hantzschia
	Lithodesmium
	Myxophyceae
	Navicula
	Nitzschia
	Pennale
	Pinnularia
	Pseudostaurosira
	Rhopalodia
	Sellaphora
	Skeletonema
	Surirella
	Synedra
	Tryblionella
	Urosolenia
	Zhoicosphenia