Otago lakes' trophic status
Lake Hayes
Lake Johnson
Lakes Onslow
Lake Wakatipu
Lake Wanaka

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ISBN 1-877265-85-3

Published November 2009

Foreword

The high quality of Otago's lakes and waterways has come to be expected by all who live and visit the region. However, areas are coming under pressure from intensive agriculture, urbanisation and water discharge practices.

To help protect water quality, the Otago Regional Council (ORC) carries out long-term water quality monitoring as part of its State of the Environment programme. Short-term monitoring programmes are also carried out in some catchments to provide more detailed information. These programmes assist regional planning and help everyone understand the need to protect water quality.

This report provides the results from short-term studies, which monitored the health of five high country lakes (Lakes Hayes, Johnson, Onslow, Wakatipu and Wanaka). With this information the ORC and local community can work together to ensure the future wellbeing of these five important lakes.

Executive summary

Otago Regional Council monitored five high country lakes in the Clutha River/Mata-Au catchment between 2006 and 2009. The monitoring of Lakes Hayes, Johnson, Onslow, Wakatipu and Wanaka was undertaken in order to detect any small changes in the trophic status of the lakes.

Trophic status is a common method for describing the health of lakes and an indicator of how much growth or productivity occurs in the lake, productivity being directly related to the availability of nutrients. Low productivity, nutrient-poor lakes usually have clear water and are called oligotrophic. Moderately productive lakes are defined as mesotrophic. Nutrient-rich lakes with high levels of productivity are called eutrophic and often can be murky and green because of algal growth.

Results from monitoring were analysed using LakeWatch software and the protocols outlined in Burns et al. 2000.

The current water quality of the lakes is shown below:

Lake	Trophic category	TLI (Trophic Level Index units)	TLI trend (TLI units per year)	PAC (Percent Annual Change %)	P-value (<0.3 = significant change)
Hayes	eutrophic	4.97 ± 0.18	-0.03 ± 0.23	0.00	1.00
Johnson	eutrophic	4.93 ± 0.20	0.16 ± 0.25	3.40 ± 15.40	0.84
Onslow	eutrophic	4.13 ± 0.20	-0.02 ± 0.15	0.00	1.00
Wakatipu					
Frankton Arm	oligotrophic	2.01 ± 0.16	-0.04 ± 0.20	2.37 ± 6.58	0.74
Queenstown Bay	oligotrophic	2.26 ± 0.18	0.03 ± 0.23	9.88 ± 9.88	0.39
Open Water	oligotrophic	2.13 ± 0.16	-0.08 ± 0.15	0.00 ± 0.00	1.00
Wanaka					
Dublin Bay	oligotrophic	2.21 ± 0.18	0.05 ± 0.24	2.59 ± 7.74	0.76
Roy's Bay	oligotrophic	2.18 ± 0.21	0.06 ± 0.22	7.26 ± 7.04	0.36
Open water	oligotrophic	2.25 ± 0.17	0.10 ± 0.27	3.33 ± 3.33	0.37

Lakes Hayes, Johnson and Onslow are categorised as eutrophic, while Lakes Wakatipu and Wanaka are classified as oligotrophic. The P-value derived from the percent annual change was >0.3 for all of the lakes, indicating that during the 2006 to 2009 monitoring period none of the lakes changed their trophic state.

Lake Hayes is a small nutrient-rich lake that has probably undergone progressive eutrophication since catchment development and intensification began. It can currently be classified as being in a eutrophic state, although two of the TLI variables (phosphorus and algal biomass) fall into the supertrophic category. The major input into Lake Hayes, Mill Creek, shows a trend of decreasing nutrient concentrations (ORC, 2008), which may be due, in part, to the implementation of the Lake Hayes Management Strategy. The condition of the lake is primarily due to historical land management.

Lake Johnson is another small, relatively shallow, nutrient-rich lake. It can currently be classified as being in a eutrophic state. Over the last three years there has been a significant decrease in total phosphorus and total nitrogen; the reason for this decrease is unclear, but the concentrations of total phosphorus, total nitrogen and algal biomass are still very high and fall into the supertrophic category.

Lake Onslow is a man-made dam in the high country. There were no increasing trends found for total phosphorus, total nitrogen or algal biomass, even though its catchment is undergoing some change from tussock to pasture. The lake can currently be classified as being in an eutrophic state with high total phosphorus values; the average total nitrogen and algal biomass values fall into the mesotrophic category.

The monitoring between 2006 and 2009 shows that Lake Wakatipu appears to be in a stable state, with little change in water quality occurring over the last three years. All three sites (Frankton Arm, Queenstown Bay and the open water site) are classified as being in an oligotrophic state, although algal biomass falls into the microtrophic category. There was a trend of increasing algal biomass in Frankton Arm and Queenstown Bay (although Frankton Arm also had a trend of increasing clarity). Rates of change are, however, extremely slow and are unlikely to have any biological significance.

Monitoring results from Lake Wanaka indicate the lake is in a stable state, with little change in water quality occurring over the last three years. All three sites (Roy's Bay, Dublin Bay and the open water site) can currently be classified as being in an oligotrophic state. There was a trend of increasing algal biomass at all three sites, although levels are so low they still fall into the microtrophic category. Roy's Bay also shows a trend of increasing clarity and total nitrogen.

Acknowledgements

Dave Black of Southern Monitoring Services Ltd, and Ross Pannell of Otago Regional Council who braved the waters of Lakes Wakatipu, Wanaka, Hayes and Johnson (whatever the weather). Also to Eryn Duffy for venturing up to Lake Onslow whenever the road was open.

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1. Introduction

There are over 20 lakes in the Otago region, ranging from small shallow coastal lakes to large inland glacial lakes. The region's lakes vary considerably in their physical, chemical and biological characteristics and are inextricably linked to their catchments. Land use activities contribute nutrients, sediment and other contaminants to the lakes, which can alter water quality and affect the diversity of plants and animals. Contaminants enter lakes through either point sources (e.g. stormwater, treated effluent), or via diffuse sources (e.g. runoff from agriculture or groundwater inputs).

With the expectation that changing land use in catchments may affect the trophic status of the lakes, a trophic level monitoring programme was undertaken by Otago Regional Council (ORC) to examine the water quality of five lakes. Trophic level monitoring allows the current state of the lakes (i.e. trophic status) to be determined and reveals any trends over time.

The five lakes monitored by the ORC are all high country lakes in the Clutha River/ Mata-Au catchment, and include the two largest natural fresh water bodies in the Otago region: Wakatipu (289 km^2) and Wanaka (180 km^2). Two small, much shallower lakes were also monitored: Hayes (2 km^2) and Johnson (0.2 km^2), as well as Lake Onslow, a dammed lake of approximately 3 km^2.

The lakes selected for trophic monitoring represent or integrate the influences of specific land uses on water quality and are representative of water quality ranging from good to poor.

The commonly accepted variables that define lake trophic condition are algal growth (chla), clarity (secchi depth) and nutrient concentrations (total phosphorus and total nitrogen). These parameters were measured on a monthly basis either in the isothermal waters or epilimnion waters of lakes that were stratified. Where appropriate, the hypolimnetic volumetric oxygen depletion (HVOD) rate was calculated from hypolimnetic dissolved oxygen profiles.

Lake stratification is the separation of a lake into distinct layers. Summer stratification, as shown in Figure 1.1, divides a lake into three zones:

- The epilimnion is the top-most layer in a thermally-stratified lake. It is warmer and typically has a higher pH and dissolved oxygen concentration than the hypolimnion. It is free to exchange dissolved gases (i.e. O_2 and CO_2) with the atmosphere. This layer receives the most light and, therefore, contains the most algae and phytoplankton, which absorb nutrients from the water. When they die, they sink into the hypolimnion.
- The thermocline is a thin but distinct layer in which temperature changes more rapidly with depth than it does in the layers above or below. Factors that affect the depth and thickness of a thermocline include seasonal weather variations, latitude and local environmental conditions.
- The hypolimnion is the dense, bottom layer of water in a thermally stratified lake. It is the layer that lies below the thermocline. Typically the hypolimnion is the coldest layer of a lake in summer, and the warmest layer during winter. Being at depth, it is isolated from surface wind-mixing during summer, and usually receives insufficient light for photosynthesis to occur.

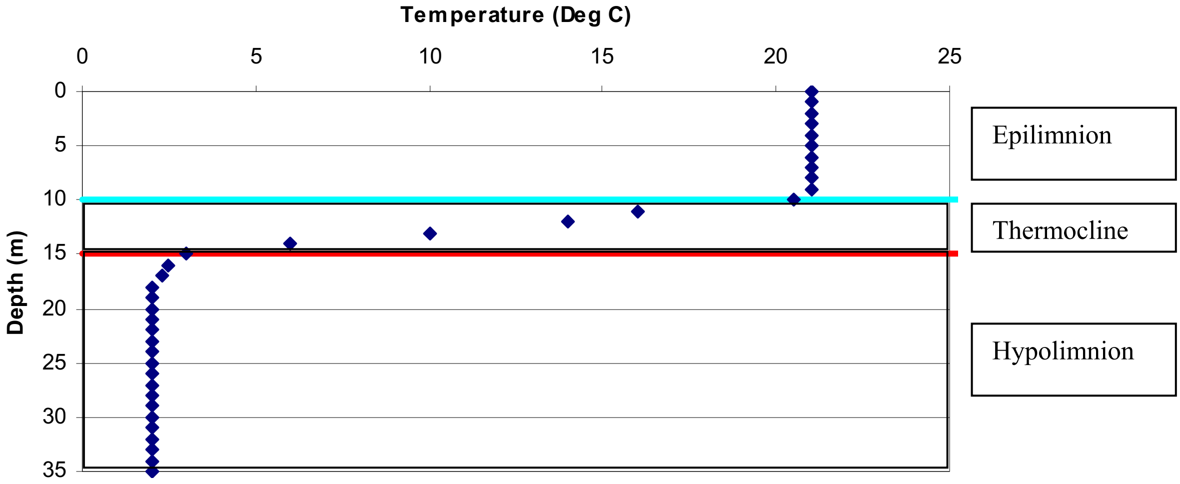

Figure 1.1 Temperature depth profile showing the three distinct layers that form in a stratified lake

Stratification traps nutrients released from bottom sediments in the hypolimnion. In the autumn, the surface cools until the water temperature evens out from top to bottom, which again allows mixing. The lake then returns to an isothermal condition.

This trophic level monitoring programme began in May 2006 and was conducted by ORC using a Hydrolab DS5X profiling instrument, a conductivity-temperature-depth (CTD) profiler/logger fitted with a Hach luminescent dissolved oxygen (LDO) probe and a chla sensor to give in-situ estimates of vertical distribution of algal biomass within the lake water column.

This report presents three years of data (May 2006 to April 2009) collected from the lakes on a monthly basis.

2. Methods

Monitoring of lake water quality was consistent with the New Zealand Lakes Water Quality Monitoring Programme (Burns et al. 2000). Water samples and site measurements were collected via boat (except for Lake Onslow, where samples were collected from the shore) on a monthly basis to ensure that the periodic variation in thermal stratification was captured as seasons changed.

In Lakes Wanaka, Wakatipu, Johnson and Hayes, a vertical profile was taken using a Hydrolab DS5X CTD meter (depth, dissolved oxygen, chla -flourescence, temperature, conductivity, pH, turbidity). To view the profile graphically, the profile was downloaded into HILLTOP manager. An example of stratified temperature profile is given in Figure 2.1 below.

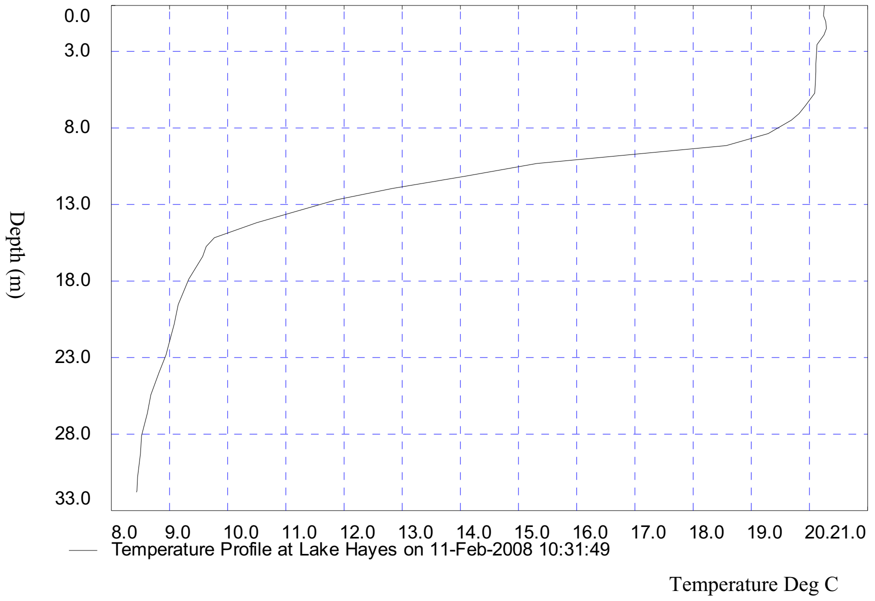

Figure 2.1 Hydrolab DS5X generated temperature profile Lake Hayes 11 February 2008

A decision was then made as to whether the lake was isothermal or stratified. If the surface and bottom lake temperatures were within 3°C the lake was generally considered to be isothermal.

The parameters routinely monitored at monthly intervals are listed below and full details are given in Appendix 1:

- Profiles of depth-related temperature, dissolved oxygen (DO), conductivity, pH, turbidity and chlorophyll fluorescence, using the Hydrolab DS5X CTD profiler
- Water clarity by secchi disc depth
- Samples at varying depths (depending on stratification status, see below) for nitrite-nitrate N (NO_3-N), ammoniacal-N (NH_4-N), total nitrogen (TN), dissolved reactive phosphorus (DRP), and total phosphorus (TP).

2.1 Quality control, data storage and analysis

Quality control measures are undertaken in accordance with ORC's internal standards, including procedures for the collection, transport and storage of samples, and methods for data verification and quality assurance to ensure consistency across the monitoring programme. Samples are analysed under contract to the ORC by Environmental Laboratory Services, which is an IANZ, LAS and Ministry of Health accredited laboratory.

Analytical methods follow the Standard Methods for the Examination of Water and Wastewater, 18th Edition (APHA 1992). For the purposes of data analysis, non-detect results (results below instrument sensitivity and reported with 'less than' values) were assumed to be half the corresponding value, and results greater than the value reported were taken as equal to the value reported. Computation of trophic level indices was undertaken using LakeWatch software (Lakes Consulting, 2000). The software incorporates the Burns trophic level assessment method (Burns et al. 2000), and provides an efficient means of elucidating key water quality indicators to determine trophic level.

3. Percent Annual Change (PAC), Trophic Level Index (TLI) and Hypolimnetic Volumetric Oxygen Depletion (HVOD) rate

The four key variables associated with determining status and trends in lake water quality are water clarity (measured by secchi depth), algal biomass (measured by chla concentrations) and the nutrient concentrations (measured by total phosphorus and total nitrogen).

Monitoring these variables allows the calculation of Percent Annual Change (PAC) and the Trophic Level Index (TLI), which can then be interpreted to indicate changes in lake water quality.

3.1 Percent Annual Change (PAC)

PAC is the average annual rate of change of clarity, algae and nutrients. It involves removing seasonal effects by plotting the data as a function of month with no regard to the year of collection. Statistical analysis enables interpretation of the probability of the average annual rate of change in lake water quality.

3.2 Trophic Level Index (TLI)

The Trophic Level Index (TLI) is widely used to measure changes in the nutrient (trophic) status of lakes. The TLI classifies the actual state of a lake at a specific time: the higher the TLI, the lower the water quality. Trophic level bands are grouped into trophic states for quantitative description, microtrophic to hypertrophic, as shown in Table 3.1.

Table 3.1 Values of variables defining the boundaries of different trophic levels (Burns et al. 2000)

Lake Type	Trophic level	Chla (mg/m^3)	Secchi depth (m)	TP (mg/m^3)	TN (mg/m^3)
Ultra-microtrophic	0.0-1.0	0.13-0.33	33-25	0.8-1.8	16-34
Microtrophic	1.0-2.0	0.33-0.82	25-15	1.8-4.1	34-73
Oligotrophic	2.0-3.0	0.82-2.0	15-7	4.1-9.0	73-157
Mesotrophic	3.0-4.0	2.0-5.0	7-2.8	9.0-20	157-337
Eutrophic	4.0-5.0	5.0-12	2.8-1.1	20-43	337-725
Supertrophic	5.0-6.0	12-31	1.1-0.4	43-96	725-1558
Hypertrophic	6.0-7.0	>31	<0.4	>96	>1558

- Microtrophic lakes are very clean, and often have snow or glacial sources.
- Oligotrophic lakes are clear and blue, with low levels of nutrients and algae.
- Mesotrophic lakes have moderate levels of nutrients and algae.
- Eutrophic lakes are green and murky, with higher amounts of nutrients and algae.
- Supertrophic lakes are fertile and saturated in phosphorus and nitrogen, and have very high algae growth and blooms during calm sunny periods.
- Hypertropic lakes are highly fertile and supersaturated in phosphorus and nitrogen. They are rarely suitable for recreation and habitat for desirable aquatic species is limited.

3.3 Hypolimnetic Volumetric Oxygen Depletion (HVOD) rate

Another important variable that is monitored is the Hypolimnetic Volumetric Oxygen Depletion (HVOD) rate. When organic matter produced in the surface waters of a lake enters the hypolimnion, it may be either permanently buried in the sediments or decomposed in the water column or sediments. In most lakes, aerobic decomposition of sedimenting organic matter consumes oxygen within the hypolimnion. As a result, the concentration of oxygen in the hypolimnion decreases throughout the period of thermal stratification. This is considered to be an important indicator of the trophic state of a lake.

Appendix 2 describes the methodology behind PAC, TLI and HVOD, and Burns et al. 2000 gives full details.

4. Lake Hayes

4.1 General description

Lake Hayes is a small relatively shallow lake which has a maximum depth of 33m and a surface area of 2.76 km^2 (Table 4.1). The major inflow is Mill Creek, which has a mean flow of approximately 0.4 cumecs. Mill Creek contributes about 75% of the inflow to the lake, 7% comes from springs flowing from the northern banks of Lake Hayes at the base of Coronet Peak and near the inlet to the lake, while runoff from adjacent slopes and precipitation contribute approximately 6% and 12%, respectively. Snowmelt contributes to the flow of Mill Creek from August to October.

Lake characteristics	
Lake type	Glacial
Lake area (km^2)	2.76
Inlet	Mill Ck
Outlet	Hayes Ck
Max depth (m)	33
Catchment area (km^2)	44

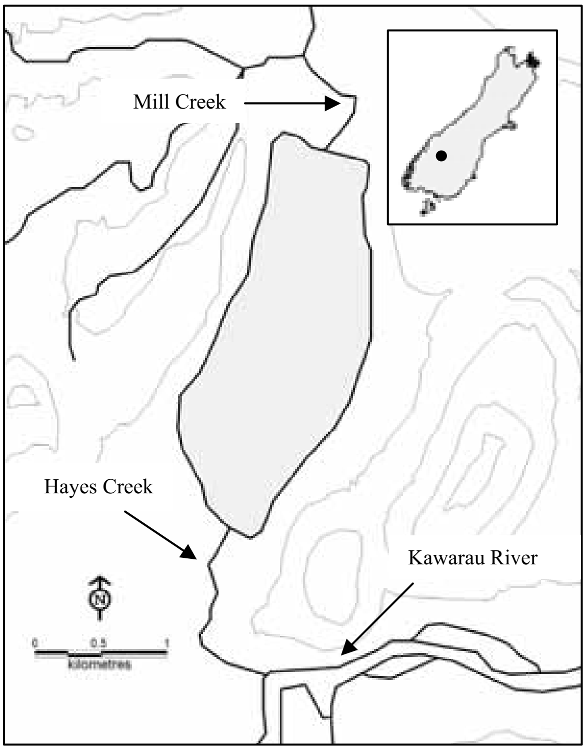

Figure 4.1 Lake Hayes: General characteristics

Lake Hayes has a catchment area of 44km^2, and the lake outlet to Hayes Creek is situated in a raupo swamp on the eastern side of the south end. Hayes Creek flows to the Kawarau River (Robertson, B.M., 1988).

Lake Hayes has a significant number of natural values, including a significant presence of trout. For this reason, it is listed in Schedule 1A of the Regional Plan: Water for Otago (the Water Plan). Cultural values associated with food gathering and processing (mahika kai) and the recognition of the lake as a treasured resource (waahi taoka) have been identified as important in Lake Hayes. These cultural values are listed in the Water Plan. Water quality has a major impact on these values.

There are no large consented discharges into Lake Hayes, but residential and commercial development is changing the nature of the catchment, which may have an impact on future water quality.

The lake is nutrient-rich (eutrophic) and shows strong thermal stratification accompanied by hypolimnetic anoxia during the summer.

4.2 Location and land use

Lake Hayes is situated 95km from the West Coast and 55km east of the Main Divide. The lake lies in the Arrow Basin, a shallow depression formed by glaciation. The catchment is used predominantly for grazing and pastoral land and is between 350m and 500m above sea level. Table 4.1 gives land use type in the catchment. The highest point in the catchment is Coronet Peak at 1646m

Table 4.1 Lake Hayes: Catchment land use

Land use % of total	
Built-up area	0.53
Deciduous hardwoods	5.31
High producing exotic grass	43.49
Indigenous forest	1.93
Lake and pond	18.39
Low producing grassland	22.97
Major shelterbelts	0.06
Matagouri	0.70
Mixed exotic shrubland	0.13
Other exotic forest	0.50
Orchard/other perennial crops	0.79
Pine forest – closed canopy	0.62
Short rotation cropland	2.06
Urban parkland/open space	0.58
Vineyard	1.93
Other	0.01

4.3 Background water quality

Many studies have been done within Lake Hayes, beginning with the work of Jolly, who conducted research in the area between 1952 and 1955. Reports and publications on Lake Hayes have also been produced by Mitchell and Burns (1972, 1974, 1979, 1980, 1981), Cook (1973), Robertson (1988) and Caruso (2000, 2001).

These studies have consistently detected a eutrophication problem within the lake, particularly that the lake has a high internal phosphorus loading as a result of historical agricultural use of the catchment and superphosphate application (Robertson, 1988, Otago Regional Council and Queenstown Lakes District Council, 1995, Caruso, 2001). The Otago Catchment Board commissioned work (Robertson, 1988 and 1989) to model nutrient loads to the lake and assess options for management.

In 1995, a Lake Hayes Management Strategy was implemented by the ORC and Queenstown Lakes District Council. This report lays out a number of policies relating to erosion and land use practices, point source discharges and the use of water within the catchment. The strategy set up a framework for five-yearly reviews, which were to include the chemical composition of the lake and any change to trophic status.

4.4 Lake Hayes: results

As discussed in section 3, the key variables used to determine the trophic level of a lake are algal biomass, clarity and nutrient concentrations. Between 2006 and 2009, ORC monitored these parameters at one site in Lake Hayes.

This section details results as follows:

- Seasonal trends for algal biomass and clarity in the epilimnion
- Seasonal trends for nutrients in both the epilimnion and hypolimnion
- Deseasonalised data and trends for algal biomass and clarity in the epilimnion
- Deseasonalised data and trends for nutrients in both the epilimnion and hypolimnion

Figures 4.2 to 4.5 show that while there is some scatter in all variables with time of year, seasonal trends are apparent.

4.5 Algal biomass (chlorophyll a [chla])

Figure 4.2 shows that concentrations of algal biomass in the epilimnion change little from March to October, but, during the summer months, concentrations increase rapidly marking a proliferation in algae. These high values did not vary from year to year.

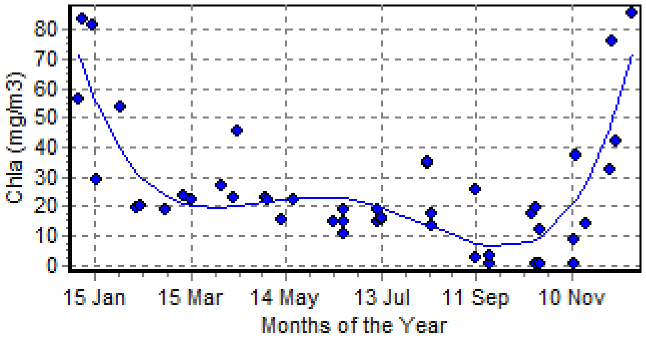

Figure 4.2 **Lake Hayes: Epilimnetic chla plotted against month of year**

4.6 Clarity (secchi depth)

Figure 4.3 shows that clarity was seasonal in pattern, with a greater depth being measured in the winter months. Over the three years, other than one measurement of 6.4m in June 2007, the depths did not vary significantly.

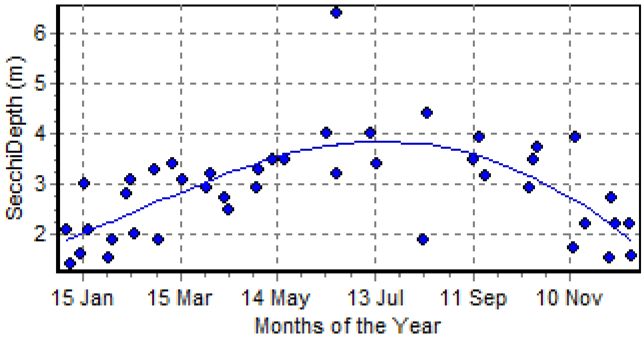

Figure 4.3 Lake Hayes: Secchi depth plotted against month of year

4.7 Nutrients (total phosphorus and total nitrogen)

Figure 4.4A shows that epilimnetic phosphorus exhibits the most scatter in the summer months, with occasional higher values in the summer months, and lower concentrations of TP found at the end of spring. There is obvious hypolimnetic TP mixing upward at the end of the stratified season (Figure 4.4B). TP values have remained consistent over the monitoring period.

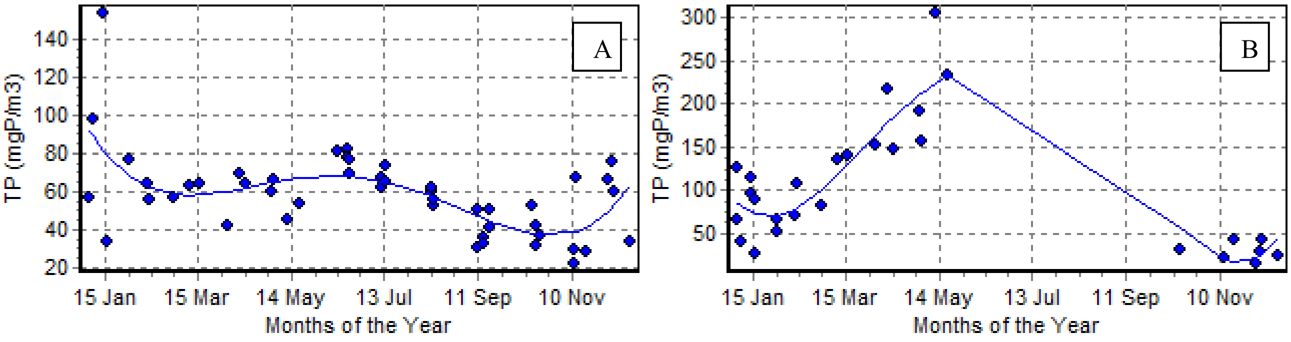

Figure 4.4 Lake Hayes: Total phosphorus plotted against month of year (A = epilimnion, B= hypolimnion)

Figure 4.5 shows that TN has a seasonal pattern, with higher concentrations of epilimnetic TN found in the summer months. There is obvious hypolimnetic TN mixing upward at the end of the stratified season (Figure 4.5B).

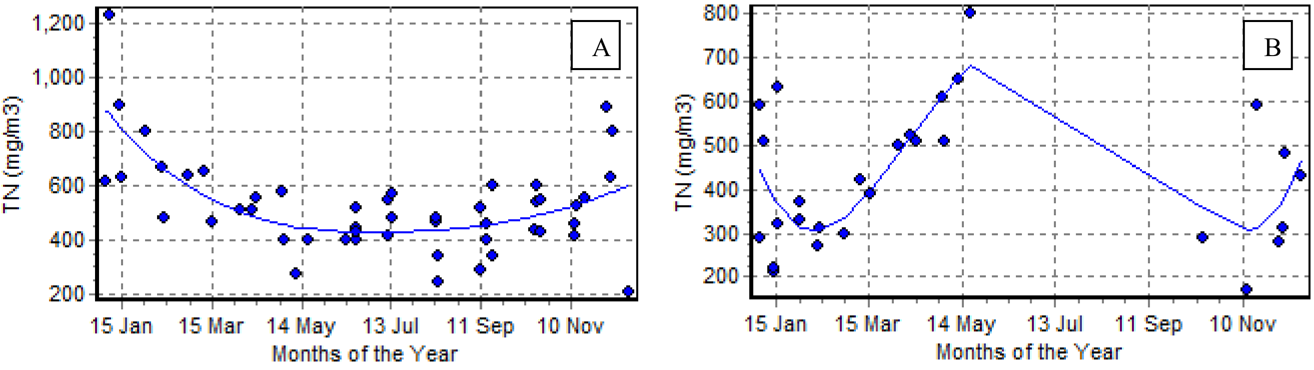

Figure 4.5 **Lake Hayes: Total nitrogen plotted against month of year (A = epilimnion, B= hypolimnion)**

Figures 4.6 to 4.9 show plots of deseasonalised data over time and any trends in the three years of data.

4.8 Algal biomass (chla) time trend

Figure 4.6 shows the plot of deseasonalised chla data over time. Chla decreased by 2.24 mg m^{-3}year^{-1} but the trend was not statistically significant.

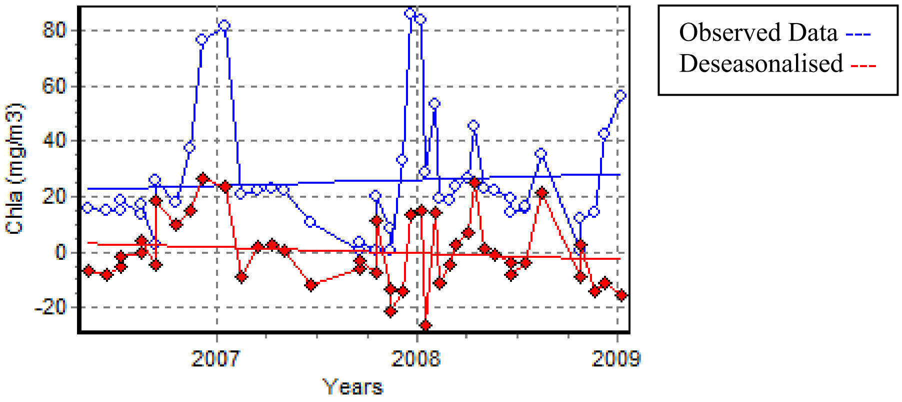

Figure 4.6 **Lake Hayes: Plot of observed and deseasonalised time trends for epilimnetic chla**

4.9 Clarity (secchi depth) time trend

Figure 4.7 shows the plot of deseasonalised SD data over time. SD decreased by 0.20m year^{-1}, but the trend was not significant.

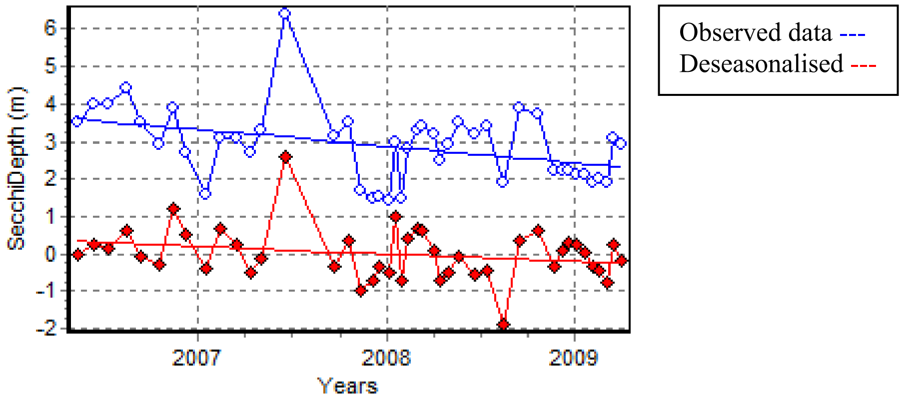

Figure 4.7 Lake Hayes: Plot of observed and deseasonalised time trends for secchi depth

4.10 Nutrients (total phosphorus and total nitrogen) time trends

Figure 4.8 shows the plots of deseasonalised TP data over time. Epilimnetic TP decreased by 5.3 mg m^{-3} year^{-1} and hypolimnetic TP decreased by 10.5 mg m^{-3} year^{-1}; neither trend was statistically significant.

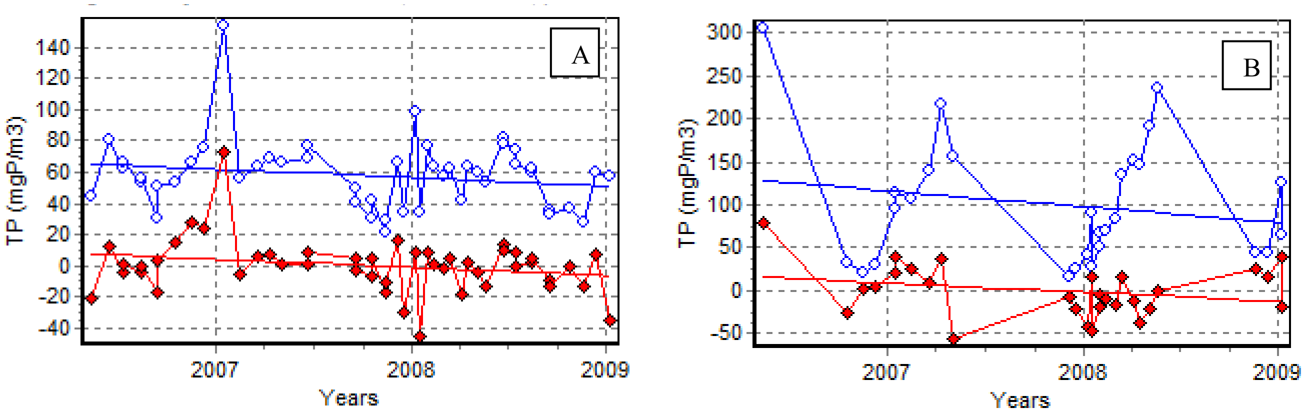

Figure 4.8 Lake Hayes: Plot of observed and deseasonalised time trends for total phosphorus (A = epilimnion, B= hypolimnion)

Observed data ---
Deseasonalised ---

Figure 4.9 shows the plot of deseasonalised TN data over time. TN increased by 35.1 mg m^{-3} year,$^{-1}$ but the trend was not statistically significant.

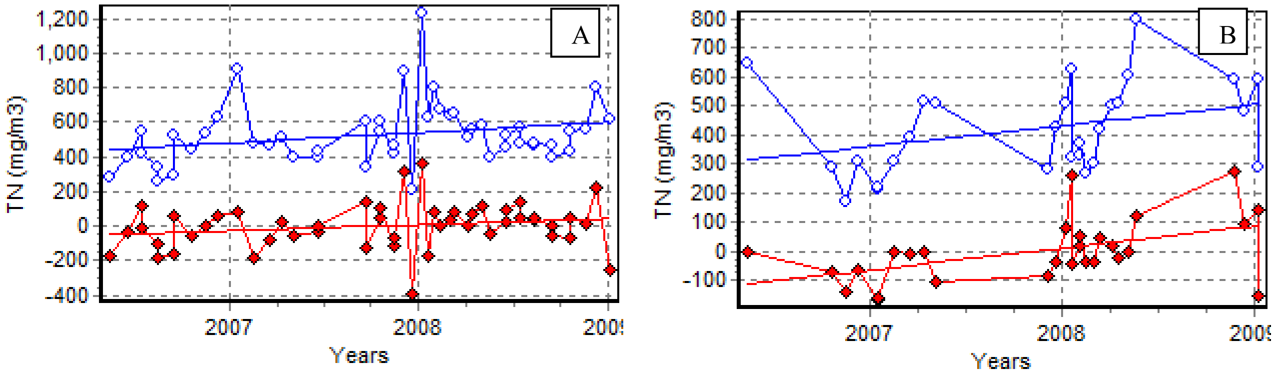

Figure 4.9 **Lake Hayes: Plot of observed and deseasonalised time trends for total nitrogen (A = epilimnion, B= hypolimnion)**

Observed data ---
Deseasonalised ---

4.11 Dissolved Oxygen (DO) and Hypolimnetic Volumetric Oxygen Depletion (HVOD) rates

HVOD rates are determined by the rate of change of DO in the hypolimnion and are calculated for the three summers when the lake was monitored. The HVOD plots are shown in Figure 4.10 and the observed HVOD rates are given by the slopes of the equations to the DO depletion rate trend lines.

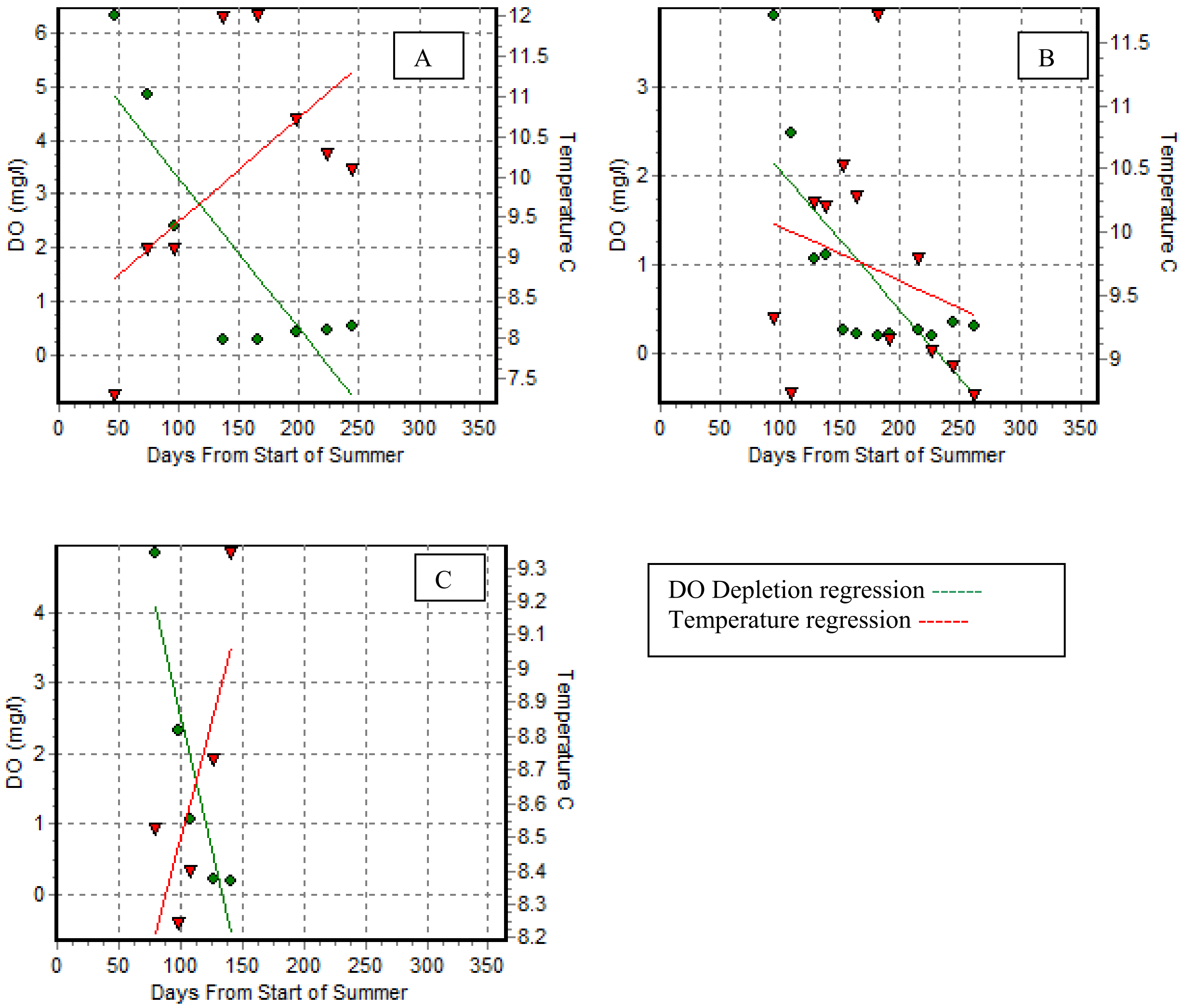

Figure 4.10 **Seasonal DO and temperature plots for the calculation of HVOD rates for Lake Hayes from 2007 (A), 2008 (B) and 2009 (C)**

These values and the average hypolimnion temperatures during the periods of HVOD rate measurement are shown in Table 4.2. Since HVOD can be changed by temperature, HVOD is adjusted to a standard temperature to make them more comparable (Burns, 1995). The standard temperature chosen for Lake Hayes was 8.9°C, as this resulted in minimum change in the rates when adjusting from observed values to temperature adjusted values.

Table 4.2 Observed and adjusted HVOD rates. Lake Hayes 2006 to 2009

Summer	Average temp Deg C	Observed DO depletion rate Deg C (mg m^3 day-1)	Observed rate at 8.9 Deg C (mg m^3 day-1)
2006/2007	10.06	28.1	25.97
2007/2008	9.72	15.6	14.82
2008/2009	8.65	76.25	77.60

Figure 4.11 shows that there was no significant trend in the HVOD rates from 2006 to 2009.

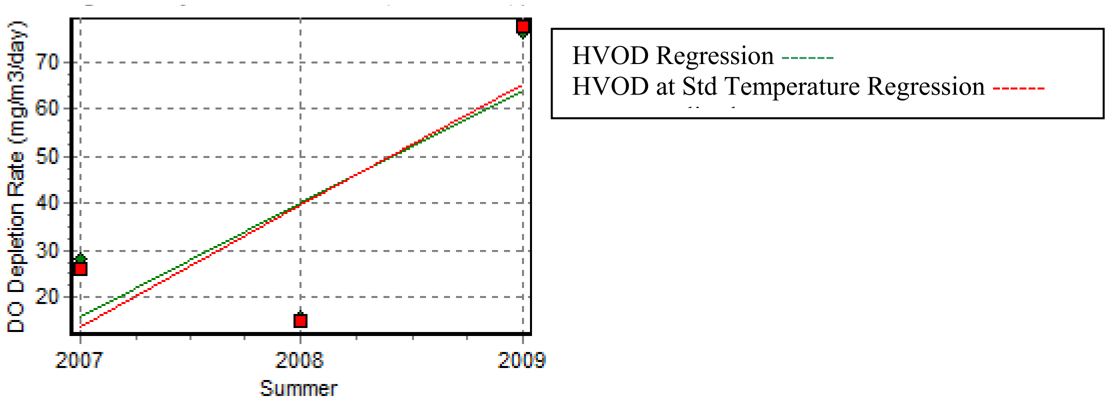

Figure 4.11 **Plot of observed HVOD rate and the HVOD rate corrected to a standard hypolimnion temperature of 8.9°C for Lake Hayes from 2006 to 2009**

Even though there was no significant trend in the HVOD rate, Figure 4.12 shows that DO concentrations in the hypolimnium change rapidly from October to January. This happens each season, with anoxic conditions then prevailing until May when the thermocline breaks down.

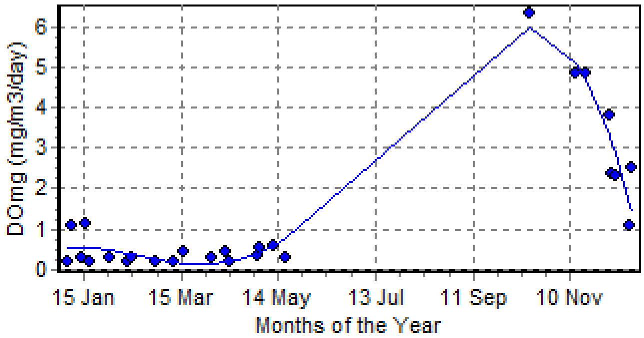

Figure 4.12 **Lake Hayes: Hypolimnetic dissolved oxygen plotted against month of year with no regard for year of collection**

4.12 Percent Annual Change (PAC): Results

The PAC values are calculated using the annual change values obtained from the slopes of the four key variables (chla, secchi depth, TN and TP) that show significant change. This calculation is described in Appendix 2.

For Lake Hayes, three of the four epilimnion variables showed a trend towards a lower trophic level; however, only PAC values calculated from significant trend lines are considered indicative of change in a particular variable. All four variables have non-significant slopes and thus the PAC values for all four variables were replaced by a value of 0.00 (Table 4.3).

Table 4.3 PAC results for Lake Hayes

Lake Hayes	Chla (mg/m^3)	SD (m)	TP (mg/m^3)	TN (mg/m^3)
Change - units per year	(-0.50)	(-0.19)	(-5.28)	(35.07)
Average over period	(24.68)	(2.95)	(57.82)	(525.71)
Percent annual change (%/year)	0.00	0.00	0.00	0.00

The decision on whether a lake has changed over time is made by looking at the p-value of the PAC average. The PAC value for the three years of monitoring Lake Hayes is 0.00% $year^{-1}$ with a p-value of 1.00, which means that the lake is not changing trophic state (Table 4.4).

Table 4.4 P-value range of PAC average

P-value range	Interpretation
<0.1	definite change
0.1 - 0.2	probable change
0.2 - 0.3	possible change
>0.3	no change

4.13 Trophic Level Index: Results

The TLI values are calculated next. This calculation is described Appendix 2. The annual average values are taken from the three years of data shown in Table 4.5.

Table 4.5 Lake Hayes: Average annual values for the four key variables

Period	Chla (mg/m^3)	SD (m)	TP (mg/m^3)	TN (mg/m^3)
May 2006 - Apr 2007	26.67	3.28	65.6	467.33
May 2007 - Apr 2008	25.96	2.81	54	577.89
May 2008 - Apr 2009	19.25	2.78	54.87	518
Averages	23.96	2.96	58.16	521.08

The trophic level values for each of the variables and TLI values generated from these numbers are shown in Table 4.6, as are the average TLI values from the two most recent years of data.

Table 4.6 Lake Hayes: Trophic level values derived from the average annual values

Period	TLc	TLs	TLp	TLn	TLI average
May 2006 - Apr 2007	5.84	4.12	5.52	4.43	4.98
May 2007 - Apr 2008	5.81	4.31	5.28	4.7	5.03
May 2008 - Apr 2009	5.48	4.33	5.3	4.56	4.92
Averages	5.71	4.25	5.37	4.56	4.97

The TLI has a time trend value of 0.03 ± 0.23 TLI units per year $^{-1}$, which shows a small upwards trend.

Table 4.6 shows how the four key variables influence the TLI. The average TLs and TLn values fall into the eutrophic category; however, the TLc and TLp values fall into the supertrophic category.

The most recent TLI value (2008 to 2009) for Lake Hayes is 4.97 TLI units, which classifies the lake as eutrophic; although this result is very close to the boundary of supertrophic, which has a TLI value of 5.0 TLI units.

4.14 Plots of other data (NNN, NH4, DRP, pH, turbidity)

Several variables other than those termed key variables were monitored as part of the programme. Figures 4.13 to 4.18 show plots of nitrite-nitrate nitrogen (NNN), ammoniacal nitrogen (NH4), dissolved reactive phosphorus (DRP), pH and turbidity. For each parameter seasonal trend results are given for both the epilimnion and hypolimnion. If any of the parameters show a significant trend over time, then these plots are also shown.

NNN is shown in Figure 4.13; this is strongly seasonal, with peak values occurring between August and November and hypolimnetic NNN showing peak values during the summer. There is no trend of change with time.

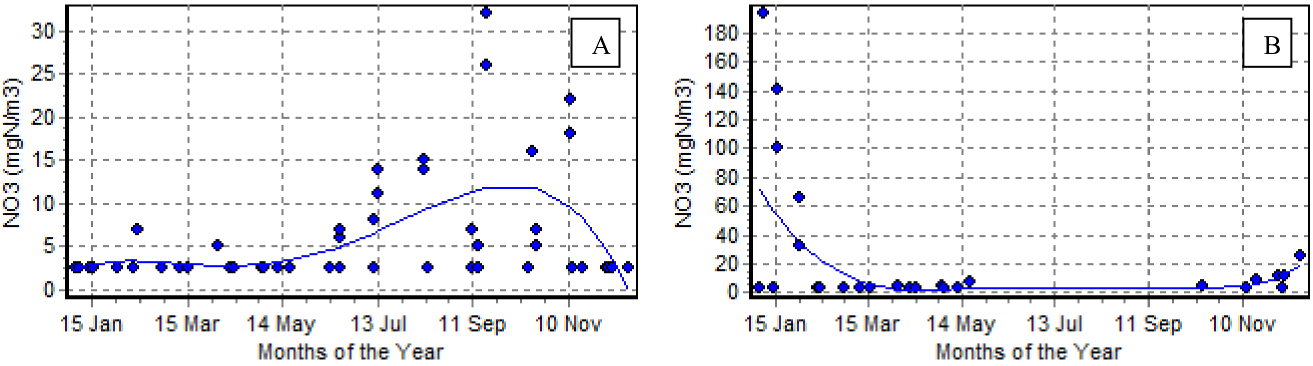

Figure 4.13 **Lake Hayes: Plot of annualised nitrite-nitrate nitrogen (A = epilimnion, B= hypolimnion)**

NH4 is shown in Figure 4.14. Ammoniacal nitrogen is most abundant in the epilimnion during the spring and is released from the sediments during anoxic conditions in the summer months.

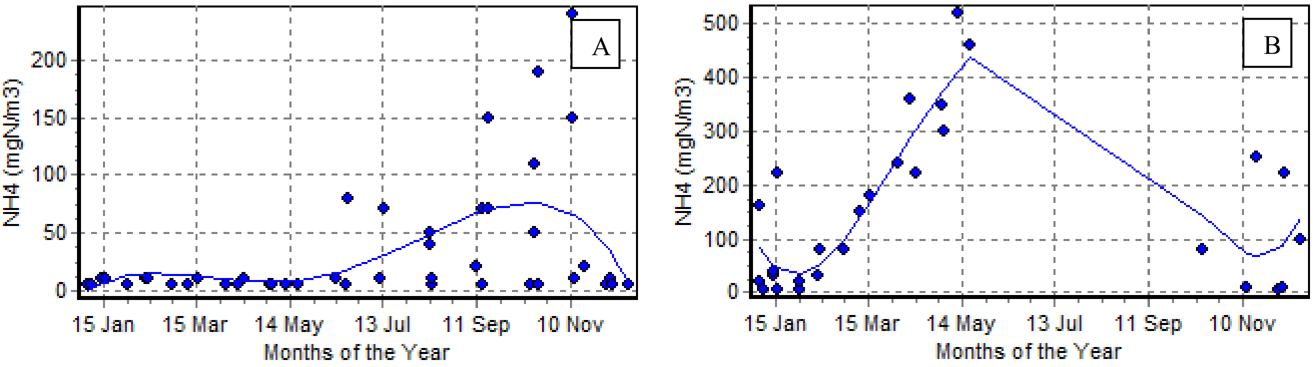

Figure 4.14 **Lake Hayes: Plot of annualised ammoniacal nitrogen (A = epilimnion, B= hypolimnion)**

DRP is shown in Figure 4.15. It shows a strongly seasonal pattern, with higher values occurring during the winter months in both the epilimnion and hypolimnion.

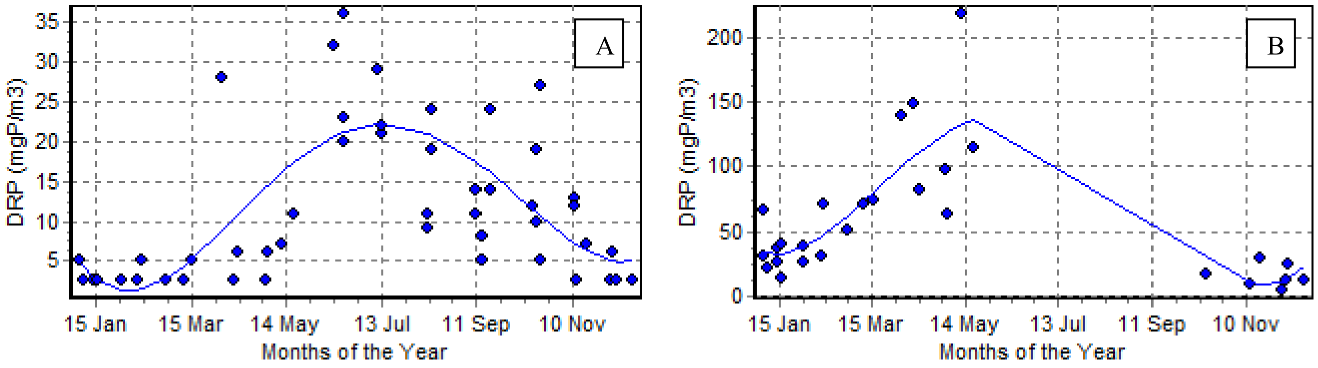

Figure 4.15 **Lake Hayes: Plot of annualised dissolved reactive phosphorus (A = epilimnion, B= hypolimnion)**

DRP has a non-significant decline of -1.48 mg P m^{-3} year; TP, on the other hand has a non-significant decline of -5.28 mg P m^{-3}, indicating that about a third of the decline in TP is probably due to a decline in DRP.

Figure 4.16 shows the epilimnetic and hypolimnetic pH conditions. Both show seasonal trends, the epilimnetic pH declining when the lower pH hypolimnetic waters mix upwards and the hypolimnetic pH declining as the hypolimnetic DO is converted into CO_2. Neither showed a trend with time.

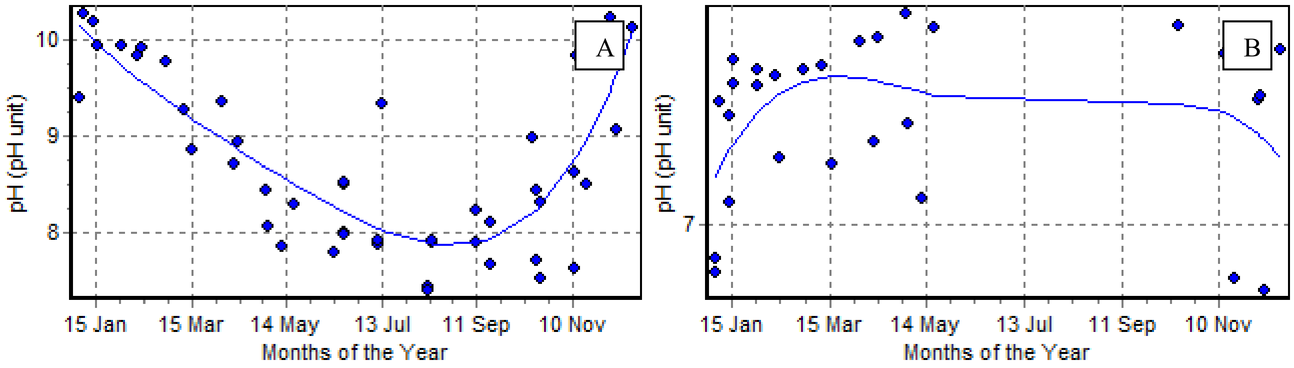

Figure 4.16 **Lake Hayes: Plot of annualised pH (A = epilimnion, B= hypolimnion)**

Figure 4.17 shows that turbidity has a strongly seasonal pattern, with high values occurring in the epilimnion during the summer months. This coincides with high algal biomass values, as shown in Figure 4.2. The significant downward trend in turbidity, as shown in Figure 4.18, does not correspond to a decline in either algal biomass or clarity, and should be treated with caution.

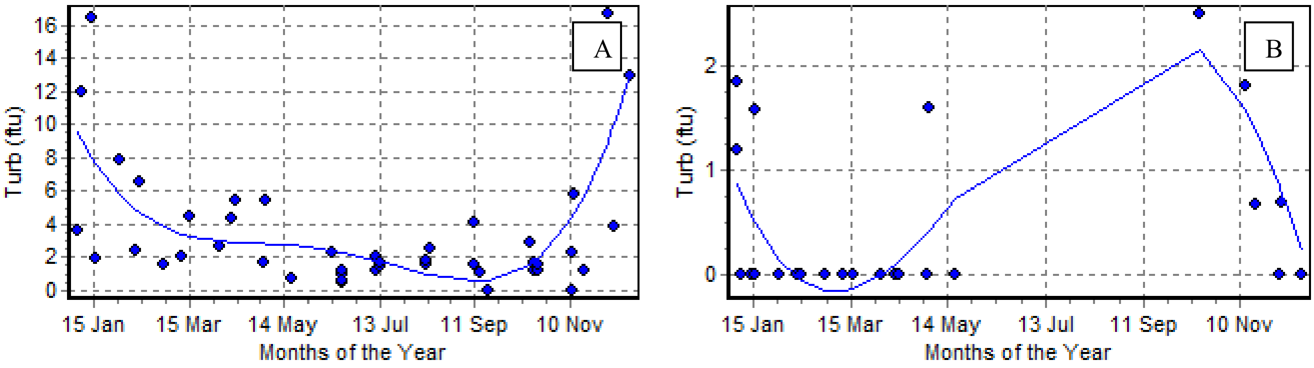

Figure 4.17 Lake Hayes: Plot of annualised turbidity (A = epilimnion, B= hypolimnion)

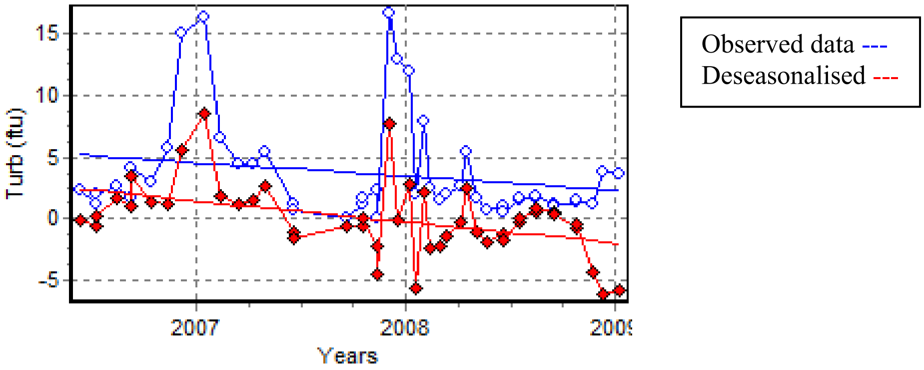

Figure 4.18 Lake Hayes: Plot of epilimnetic turbidity time trend

4.15 Discussion

Eutrophication of water bodies is a common problem in modified catchments and Lake Hayes is no exception. The Lake Hayes Management Plan (Department of Lands and Survey, 1982) ranked Lake Hayes as one of the most eutrophic of 72 lakes in New Zealand.

The physical stratification of Lake Hayes for seven months of each year into distinct density layers determines much of what happens to algal growth, fisheries habitat and the distribution of nutrients and oxygen within the lake. The stratification seals off the deeper waters from oxygen in the air and, by late January, the hypolimnetic oxygen consumption resulting from respiration causes the oxygen concentration to drop to zero (Figure 4.12).

This large decline in oxygen concentration restricts fish and other animals to the upper layers of water during much of the summer-autumn period. It is also responsible for the internal release of large concentrations of biologically available phosphorus and nitrogen from the sediments into the hypolimnion. This situation is especially apparent in Lake Hayes during the summer-autumn stratified period when mixing with the high nutrient waters of the hypolimnion is restricted. In June when the lake mixes, these nutrients from the deep water are then available for algal growth in the light saturated surface waters. The three-year monitoring programme (2006 to 2009) revealed algal blooms and a deoxygenated hypolimnion. These are the primary symptoms of eutrophication, which is probably directly related to the phosphorus available in the lake (due, mainly, to agricultural activities of the past).

The phosphorus content of the surface waters decreases as the summer progresses (Figure 4.19) because of its removal by organic material settling out of the epilimnion into the bottom waters. However, when oxygen in the hypolimnion is used up, there is a massive release of phosphorus from the sediments to the overlying waters, giving the high hypolimnetic phosphorus concentrations observed in February to May (Figure 4.19B). In June, the epilimnion cools, the lake waters mix and the lake enters its isothermal phase, which lasts until November.

Thus in June, the concentration of phosphorus in the surface waters increases because of the incorporation of some of the phosphorus previously held only in the bottom waters. Figure 4.19A clearly shows an increase in epilimnetic phosphorus occurring in June. As the isothermal period proceeds, the phosphorus concentrations slowly decrease because particulate material settles out from the lake waters to the sediments.

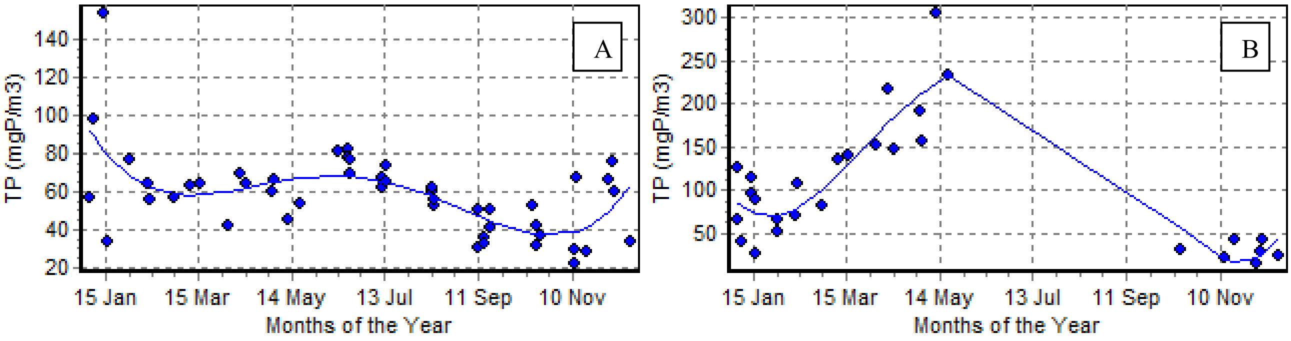

Figure 4.19 Lake Hayes: TP plotted against month of year (A = epilimnion, B= hypolimnion)

In stratified lakes, increasing ammoniacal nitrogen values are often associated with the increasing prevalence of anoxic conditions which are the result of increasing eutrophication. The anoxic conditions cause the denitrification of nitrate to ammonia. Ammoniacal nitrogen is also released from the sediments during anoxic conditions (Figure 4.20).

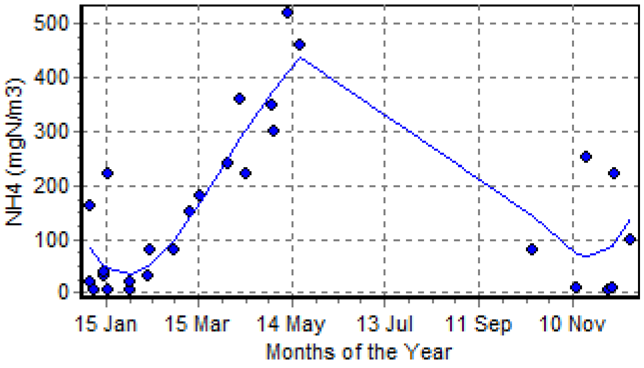

Figure 4.20 Lake Hayes hypolimnion NH4 plotted against month of year

Ammonia (NH_3) is the main toxic component for aquatic organisms, the prevalence of which is dependent on the pH, temperature and salinity of the water. pH is particularly important in terms of ammoniacal nitrogen toxicity to fish. Figure 4.21A shows the pH depth profile for January 2008; the extremely high pH values were caused by the dinoflagellate C*eratium*. This algal biomass is shown in Figure 4.21B as chla concentrations. During this time, epilimnion temperatures were in excess of 20°C (Figure 4.21C). This combination of high pH and high temperature meant that ammonia toxicity was also almost certainly present in Lake Hayes. As NH_3 was not monitored as a stand alone parameter, it is unclear whether the theoretical conversion concentration is a true representation of the amount of ammonia toxicity present in the lake.

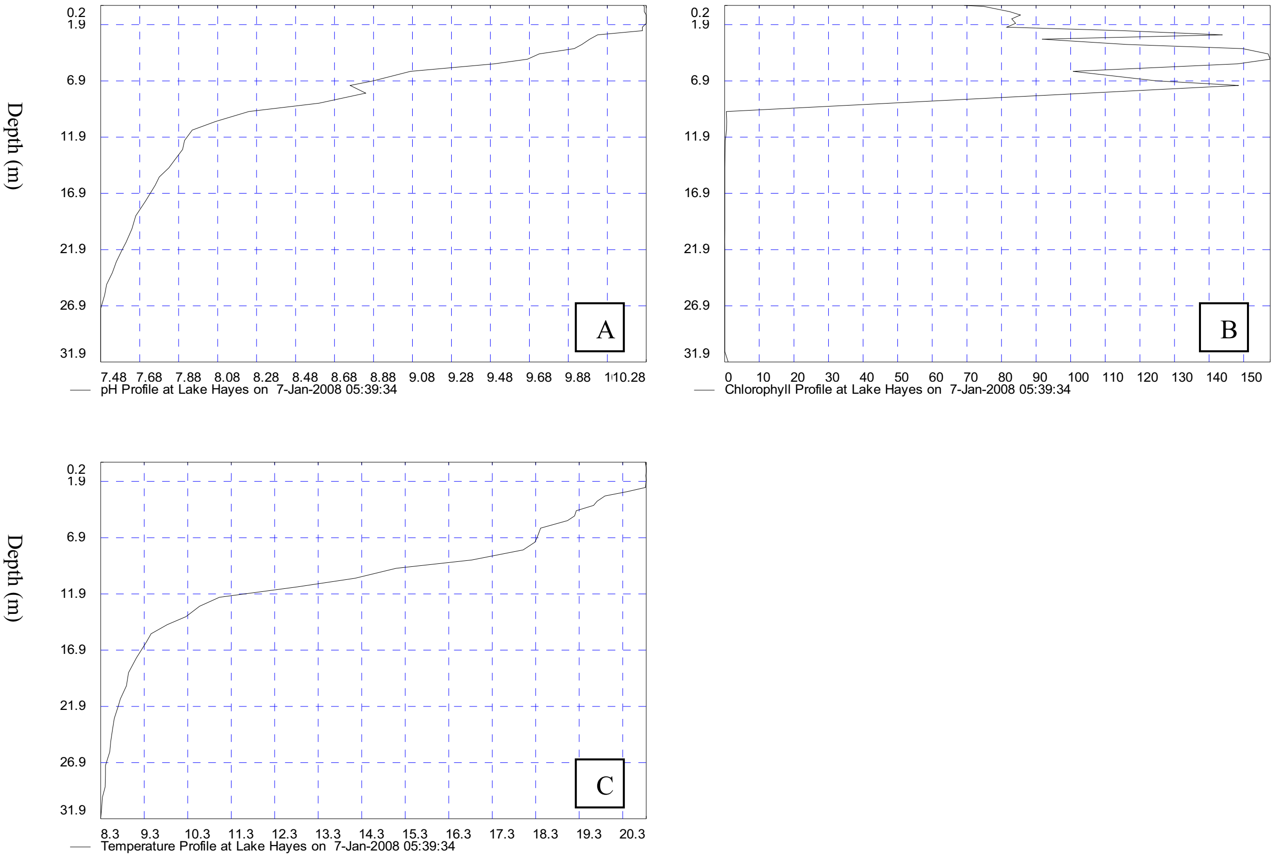

Figure 4.21 pH (A), chla (B), temperature (C) profiles. Lake Hayes January 2008

During this study, the algal species found in Lake Hayes was the dinoflagellate *Ceratium*, which caused a red tide during the summers of 2006, 2007 and 2008. While this red tide is not toxic, it can deplete resources in its environment, causing strain on the ecosystem. This is a change from the toxic blue-green algae (*Anabaena flos-aquae*) that were recorded in 1971-72 (Burns and Mitchell, 1974), 1974-75 (Graham and Burns, 1983) and 1984-85 (Robertson 1988). The reason for the change in algae species is unclear: nutrients in the epilimnion may have decreased, making *Ceratium*, which are motile, go down to the hypolimnion to obtain nutrients. However, they are also mixotrophs, obtaining food both through photosynthesis and phagocytosis, and so are able to feed when nutrients are low. However, if anything changes in the lake (zooplankton, climate, temperature), then the dominant species of algae is also likely to change.

Figure 4.22 shows that NNN hypolimnetic concentrations are higher during the months of November to March during oxygenated conditions and then lower when the anoxic conditions prevail.

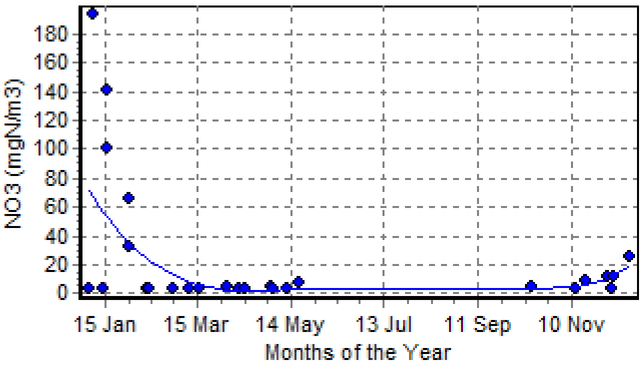

Figure 4.22 Lake Hayes: Hypolimnetic NNN concentrations plotted against month of year

It is useful to compare the results of the trophic monitoring undertaken between 2006 and 2009 with the data collected for the New Zealand lakes monitoring programme between 1992 to 1995 (Burns et al. 2000). The results are given in Table 4.7.

Table 4.7 TLI values for Lake Hayes for two time periods: 1992 to 1995 and 2006 to 2009

Period	Chla mg/m^3	SD m	TP mg/m^3	TN mg/m^3	TLc	TLs	TLp	TLn	TLI av.
May 92 - Apr 93	12.39	2.84	36.44	410.8	5	4.3	4.78	4.26	4.58
May 93 - Apr 94	5.15	3.91	33.92	446.11	4.03	3.9	4.69	4.36	4.25
May 94 - Apr 95	5.61	3.19	28.67	375.46	4.12	4.16	4.47	4.14	4.22
Averages	7.72	3.31	33.01	410.79	4.38	4.12	4.65	4.25	4.35

TLI value = 4.35 ± 0.09 TLI units TLI trend = -0.18 ± 0.11 TLI units per year P-value = 0.1244

Period	Chla mg/m^3	SD m	TP mg/m^3	TN mg/m^3	TLc	TLs	TLp	TLn	TLI av.
May 06 - Apr 07	26.67	3.28	65.6	467.33	5.84	4.12	5.52	4.43	4.98
May 07 - Apr 08	25.96	2.81	54	577.89	5.81	4.31	5.28	4.7	5.03
May 08 - Apr 09	19.25	2.78	54.87	518	5.48	4.33	5.3	4.56	4.92
Averages	23.96	2.96	58.16	521.08	5.71	4.25	5.37	4.56	4.97

TLI value = 4.97 ± 0.18 TLI units TLI trend = -0.03 ± 0.23 TLI units per year P-value = 0.8974

Table 4.8 Lake Hayes. Interpretation of PAC and TLI values for two time periods: 1992 to 1996 and 2006 to 2009

Time Period	1992 to 1996	2006 to 2009
PAC value	-9.99 ± 7.46 % per year P-value = 0.25	0.00 ± 0.00 % per year P-value = 1.00
TLI value	TLI value = 4.35 ± 0.09 TLI units	TLI value = 4.97 ± 0.18
TLI time trend	-0.18 ± 0.11 TLI units per year-1	-0.03 ± 0.23 TLI units per year-1
Interpretation of PAC and TLI value	Indicates the lake is eutrophic, with possible change to a lower trophic state	Indicates the lake is eutrophic, with no indication of a change to a different trophic state

Although the trophic level has remained the same in the two monitoring periods, the TLI value is higher in the 2006 to 2009 period than in the 1992 to 1995 period. Average concentrations of clarity, algal biomass and nutrients have all increased. The levels of chla are much larger than in 1992 to 1995, due to the prevalence of algal blooms during this monitoring period. With nutrient levels as high as they are, algal blooms in Lake Hayes should be considered a normal part of the lake year.

Average levels of TP and algal biomass are indicative of a supertrophic state, whereas levels of TN and clarity fall into the eutrophic category. Overall lake water quality is classified as eutrophic. Nitrogen levels are high, and there is a trend (non significant) of increasing nitrogen of 35 mg m^{-3} $year^{-1}$; thus TN concentrations are unlikely to be exhibiting much control over the algal biomass. With increasing nitrogen concentrations, it is unlikely that there will be a drop in chla concentrations.

Average PAC values during the 2006 to 2009 monitoring period indicate that there has been no change in lake water quality since 2006.

Dissolved oxygen, pH, turbidity, nitrite-nitrate nitrogen and dissolved reactive phosphorus were also analysed, but no significant trends were found. A lack of trends in these variables and a lack of any strong trends in the key variables may indicate that the lake is in a relatively stable state.

The two main concerns for the lake are:

- The combination of high temperature, low dissolved oxygen and high pH, which have had an acutely negative effect on aquatic biota during the summer.
- The depth of the anoxic hypolimnion, which has increased between the two monitoring periods. From 1992 to 1995, the oxygen concentration dropped below 2mg/l from a depth of 12m; however, during the 2006 to 2009 period, the depth of anoxic water had increased, starting from a depth of 6m. This will have major impacts on aquatic biota.

4.16 Conclusion

Lake Hayes is a small, relatively shallow, nutrient-rich lake that has likely undergone progressive eutrophication since catchment development and intensification began. The monitoring between 2006 and 2009 shows that the lake appears to be in a relatively stable state with little change in water quality occurring over the last three years. It can currently be classified as being in a eutrophic state, although two of the TLI variables (phosphorus and algal biomass) fall into the supertrophic category. Analysis of key variables shows a trend of increasing TN, but small decreases in the other variables. However, rates of changes are extremely slow and are likely to have little biological significance.

In both 1992 to 1995 and this monitoring period, Lake Hayes was classified as eutrophic; however, due to the algal blooms over the last three years, it is now close to being classified as supertrophic. A water body's trophic state is largely determined by nutrient inputs from the surrounding catchment (Barnes, 2002). The major input into Lake Hayes is Mill Creek, which shows a trend of decreasing nutrient concentrations (ORC, 2007); this decreasing trend may be due to the success of the Lake Hayes Management Strategy. There is still further opportunity for improvements within the Mill Creek catchment, in particular, preventing loss of sediment from earthworks in the rapidly developing upstream catchment. However, without intervention, a significant improvement in lake water quality is probably unlikely due to historical agricultural land use practices in the catchment.

5. Lake Johnson

5.1 General description

Lake Johnson is a small relatively shallow lake with a maximum depth of 27m, and a surface area of 0.2 km^2. The catchment of the lake is small (1.9 km^2), with only two houses. Lake Johnson has no natural in-flowing or out-flowing water; the only sources of water are seepage and flow in several temporary streams and irrigation channels. (Mitchell and Burns, 1972). Figure 5.1 gives the general characteristics and location of Lake Johnson.

Lake Characteristics	
Lake Type	Glacial
Lake area (km^2)	0.2
Inlet	None
Outlet	None
Max depth (m)	27
Catchment area (km^2)	1.9

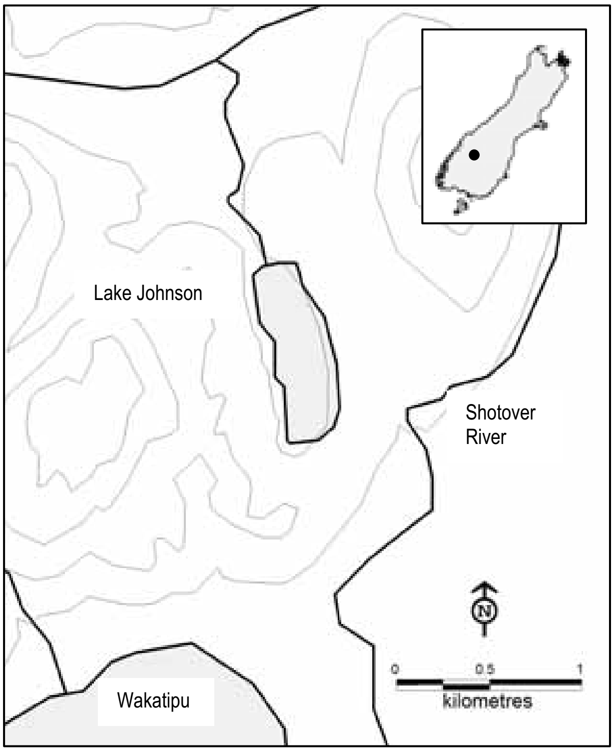

Figure 5.1 Lake Johnson: General characteristics

Lake Johnson has a number of natural values including significant presence of trout. For this reason, it is listed in the Water Plan. Water quality has a major impact on these values. There are no large consented discharges into Lake Johnson.

Lake Johnson is nutrient-rich, stratifies thermally in summer and circulates fully in winter and early spring. The hypolimnion becomes completely deoxygenated by late summer. Lake Johnson is unusual in that during early summer, a second layer of deoxygenated water occurs in the thermocline (Mitchell and Burns 1979), while the upper hypolimnion remains oxygenated.

5.2 Location and land use

Lake Johnson is situated about 90km from the west coast near Queenstown in Central Otago. It lies 392m above sea level and occupies a deep rock-bound depression in glaciated schistose terrain. The area is characterised by warm sunny summers and cool winters; in severe winters, ice forms on the lake.

The catchment is used predominantly for grazing and pastoral land. Table 5.1 gives land use type in the catchment.

Table 5.1 Lake Johnson: Catchment land use

Land use	% of Total
Deciduous hardwoods	2.21
High producing exotic grass	67.82
Lake and pond	17.72
Low producing grassland	2.49
Matagouri	2.63
Pine forest – closed canopy	1.15
Tall tussock grassland	5.97

5.3 Background: water quality

Mitchell and Burns (1972) conducted research in the area during 1969 to 1971. It was concluded that the lake was more eutrophic than its close neighbour, Lake Hayes, and that Lake Johnson had a high internal phosphorus loading as a result of agriculture, as there was no other significant human influence in the catchment area (Mitchell et al. 1972).

Mitchell and Burns (1972) also stated that the lake is of considerable limnological interest because:

- the bottom water in summer is colder than that of any other New Zealand lake for which figures are available
- it develops a bimodal oxygen profile in summer, which is possibly unique in that oxygen disappears completely from the thermocline, while part of the hypolimnion is still well oxygenated
- water in the thermocline is sometimes found to be coloured pink, due to photosynthetic bacteria, a phenonmenon which has not been recorded elsewhere in New Zealand

5.4 Lake Johnson: Results

As discussed in section 3, the four key variables used to determine the trophic level of a lake are algal biomass, clarity and nutrient concentrations. Between 2006 and 2009, ORC monitored these parameters at one site in Lake Johnson.

This section details results as follows:

- Seasonal trends for algal biomass and clarity in the epilimnion
- Seasonal trends for nutrients in both the epilimnion and hypolimnion
- Deseasonalised data and trends for algal biomass and clarity in the epilimnion
- Deseasonalised data and trends for nutrients in both the epilimnion and hypolimnion

Figures 5.2 to 5.5 show that while there is some scatter in all variables with time of year, seasonal trends are apparent.

5.5 Algal biomass (chla)

Figure 5.2 shows that concentrations of algae increased rapidly when the lake stratified in spring, with the highest concentrations found between January and March. During the winter months, concentrations are low. These high summer values did not vary from year to year.

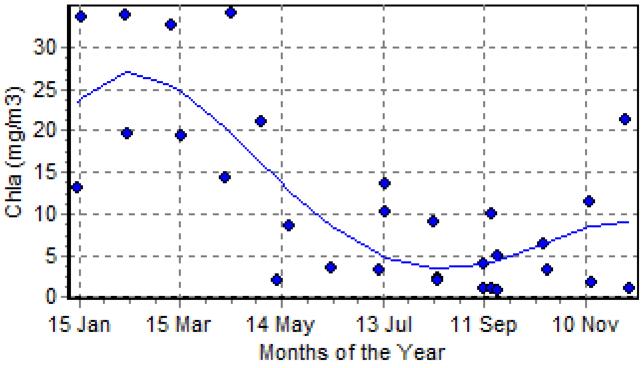

Figure 5.2 Lake Johnson Epilimnetic chla plotted against month of year

5.6 Clarity (secchi depth)

Figure 5.3 shows that clarity was seasonal in pattern with a greater depth being measured in the winter months. Over the three years, the depths did not vary significantly.

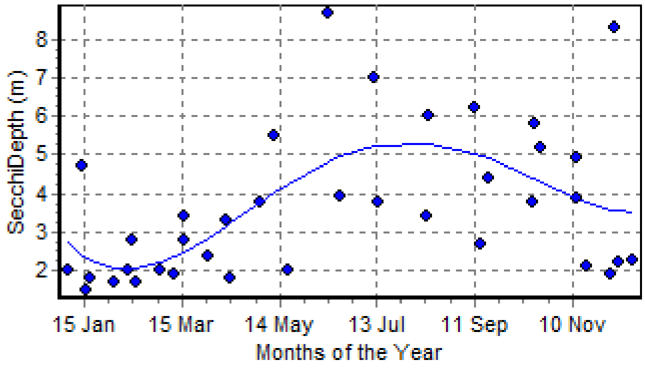

Figure 5.3 Lake Johnson: Secchi depth plotted against month of year

5.7 Nutrients (total phosphorus and total nitrogen)

Figure 5.4A shows that epilimnetic phosphorus exhibits seasonal patterns, with higher values generally found in the winter months when the lake is fully mixed. There is also some hypolimnetic TP mixing upward at the end of the stratified season (Figure 5.4B). TP values have not changed over the monitoring period.

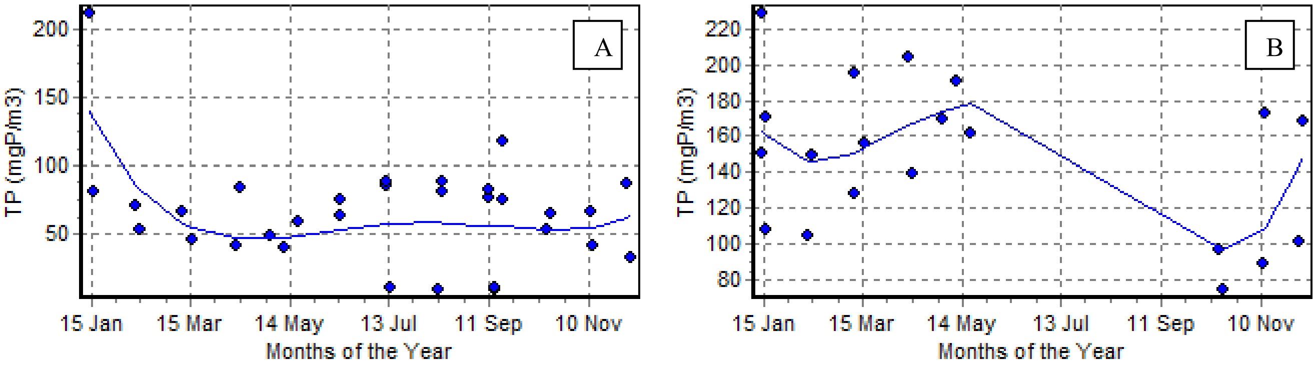

Figure 5.4 Lake Johnson: Total phosphorus plotted against month of year (A = epilimnion, B= hypolimnion)

Figure 5.5 shows a seasonal pattern, with higher concentrations of epilimnetic TN found in the summer months. TN in the hypolimnion was much higher than in the epilimnion, peaking just before the winter turnover and at a minimum in spring.

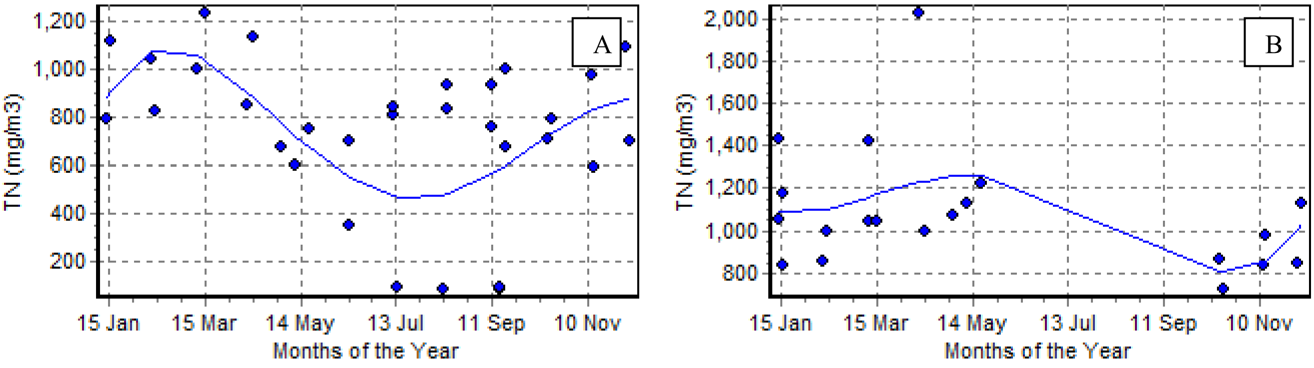

Figure 5.5 **Lake Johnson: Total nitrogen plotted against month of year (A = epilimnion, B= hypolimnion)**

Figures 5.6 to 5.9 show plots of deseasonalised data over time and any trends in the three years of data.

5.8 Algal biomass (chla) time trend

Figure 5.6 shows the plot of deseasonalised chla data over time. Chla increased significantly by 5.23 mg $m^{-3}year^{-1}$.

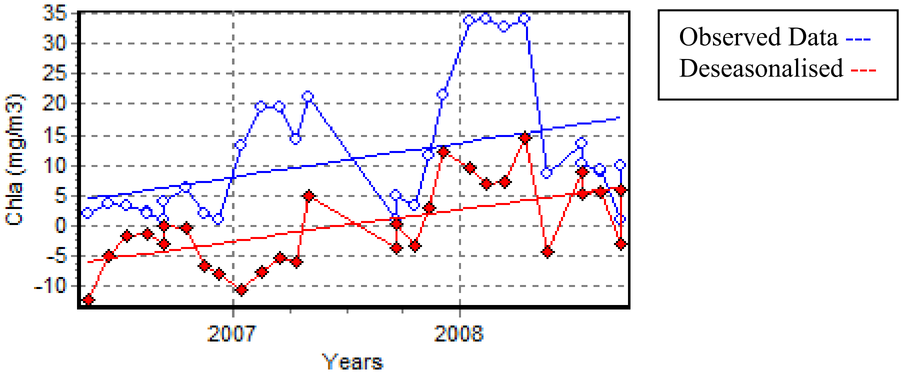

Figure 5.6 **Lake Johnson: Plot of observed and deseasonalised time trends for chla**

5.9 Clarity (secchi depth) time trend

Figure 5.7 shows the plot of deseasonalised SD data over time. SD decreased significantly by 0.98 m year^{-1}.

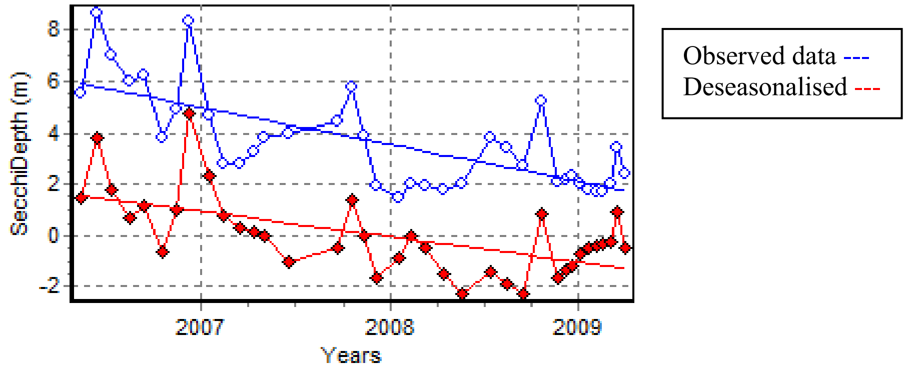

Figure 5.7 Lake Johnson: Plot of observed and deseasonalised time trends for SD

5.10 Nutrients (total phosphorus and total nitrogen) time trends

Figure 5.8 shows the plots of deseasonalised TP data over time. Epilimnetic TP decreased by 21 mg m^{-3} year^{-1} and hypolimnetic TP decreased by 29 mg m^{-3} year^{-1}; both trends were significant.

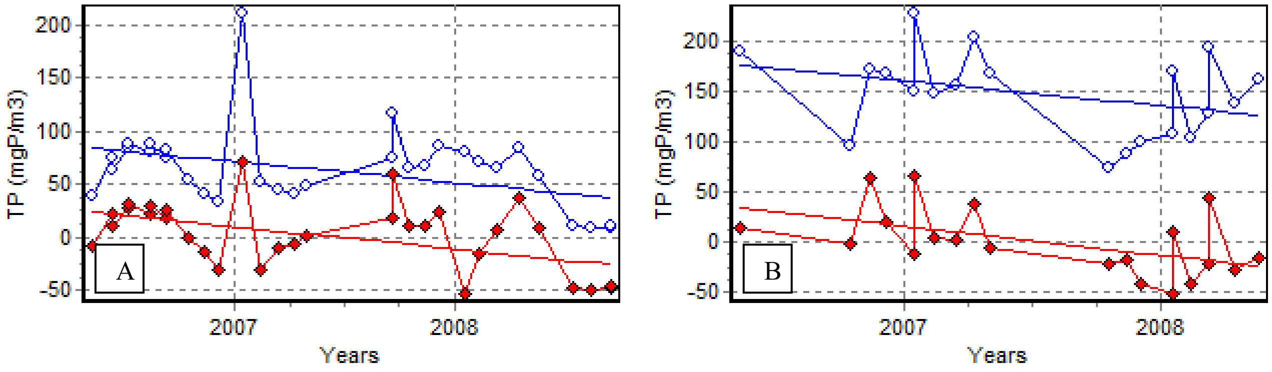

Figure 5.8 Lake Johnson: Plot of observed and deseasonalised time trends for TP (A = epilimnion, B= hypolimnion)

Figure 5.9 shows the plot of deseasonalised TN data over time. Epilimnetic TN decreased by 171 mg m^{-3} year^{-1} and hypolimnetic TN decreased by 101 mg m^{-3} year^{-1}. Only the epilimnetic trend was statistically significant.

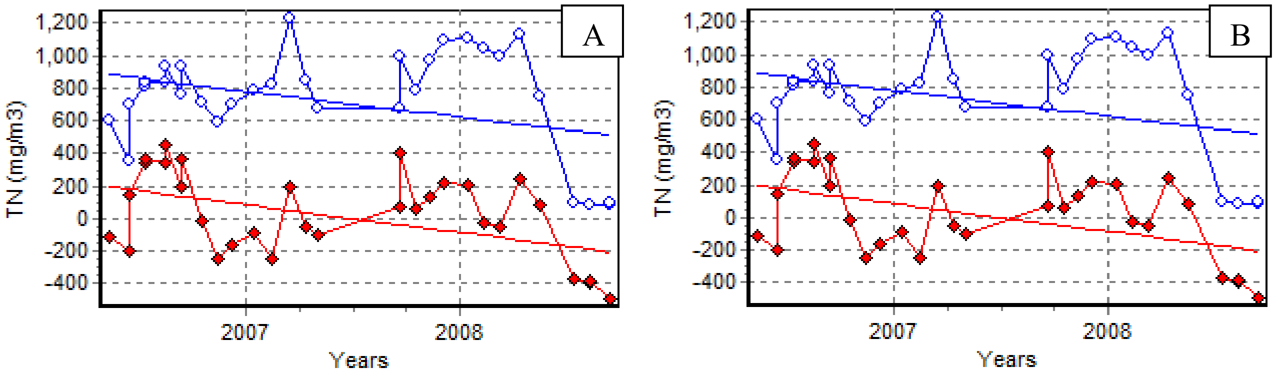

Figure 5.9 **Lake Johnson: Plot of observed and deseasonalised time trends for TN (A = epilimnion, B= hypolimnion)**

Observed data ---
Deseasonalised ---

5.11 Dissolved Oxygen (DO) and Hypolimnetic Volumetric Oxygen Depletion (HVOD) rates

HVOD rates are determined by the rate of change of DO in the hypolimnion. HVOD rates are calculated for the three summers when the lake was monitored. The HVOD plots are shown in Figure 5.10 and the observed HVOD rates are given by the slopes of the equations to the DO depletion rate trend lines

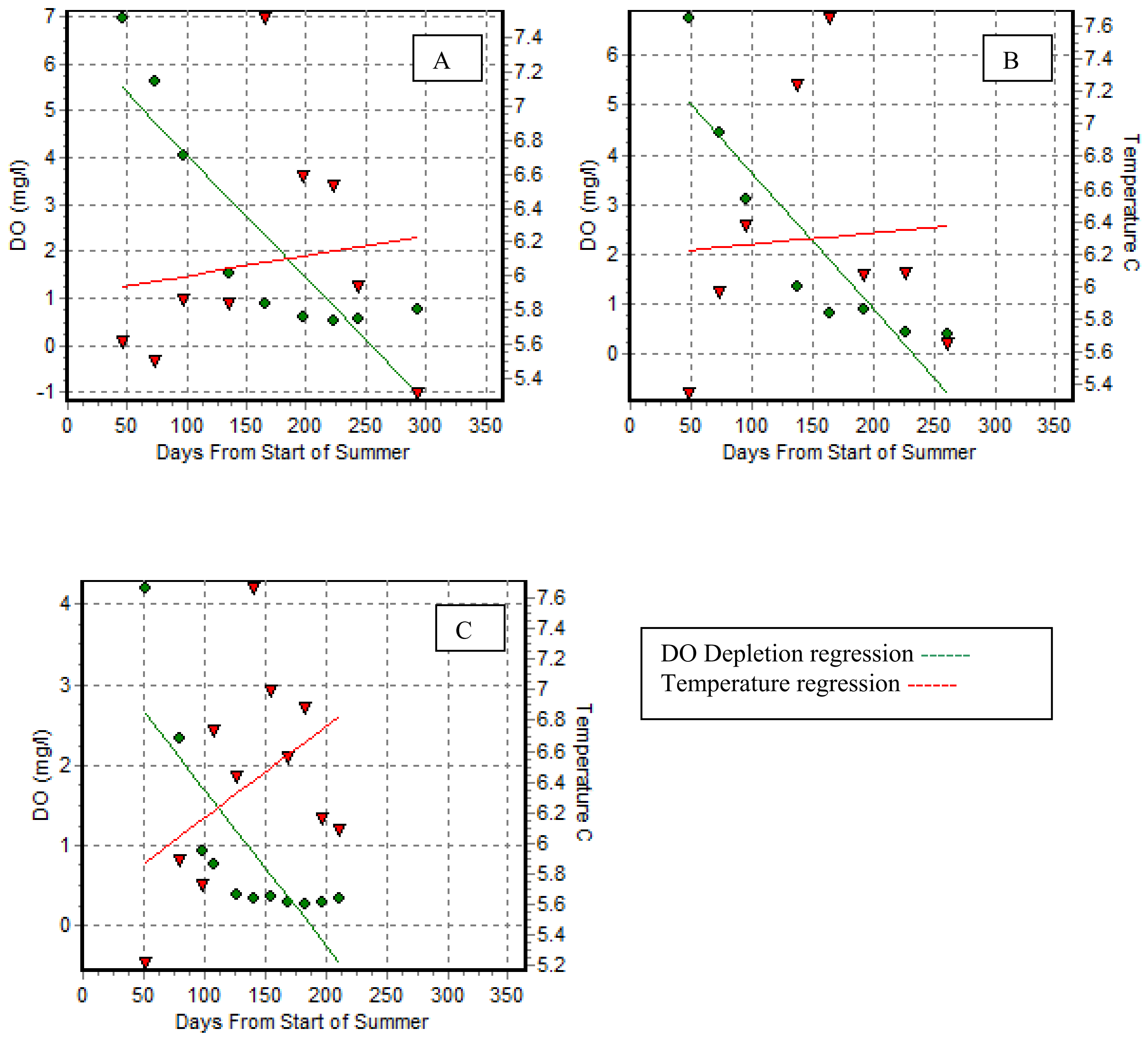

Figure 5.10 Seasonal DO and temperature plots for the calculation of HVOD rates for Lake Johnson from 2007 (A), 2008 (B) and 2009 (C)

These values and the average hypolimnion temperatures during the periods of HVOD rate measurement are shown in Table 5.2. Since HVOD can be changed by temperature, the rates have been adjusted to a standard temperature to make them more comparable (Burns 1995). The standard temperature chosen for Lake Johnson was 6.2°C, as this resulted in minimum change in the rates when adjusting from observed values to temperature adjusted values.

Table 5.2 Observed and adjusted HVOD rates. Lake Johnson 2006 to 2009

Summer	Average temp °C	Observed DO depletion rate °C (mg m^3 day^{-1})	Observed rate at 8.9°C (mg m^3 day^{-1})
2006/2007	6.075	26.3	26.5
2007/2008	6.294	27.4	27.2
2008/2009	6.395	19.3	19.0

Figure 5.11 shows that there was no significant trend in the HVOD rates from 2006 to 2009.

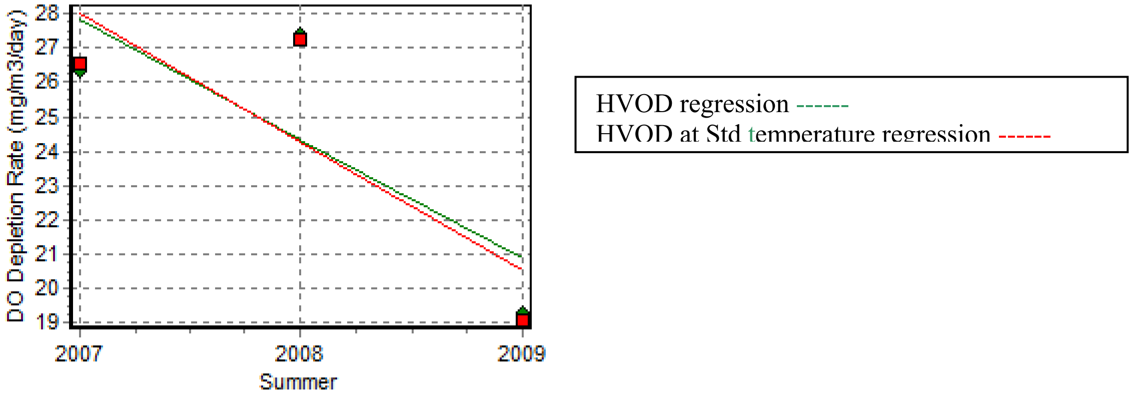

Figure 5.11 Plot of observed HVOD rate and the HVOD rate corrected to a standard hypolimnion temperature of 6.2°C for Lake Johnson from 2006 to 2009

Even though there was no significant trend in the HVOD rate, Figure 5.12 shows that DO concentrations in the hypolimnium change rapidly from October to January. This happens each season, with anoxic conditions then prevailing until May when the thermocline breaks down.

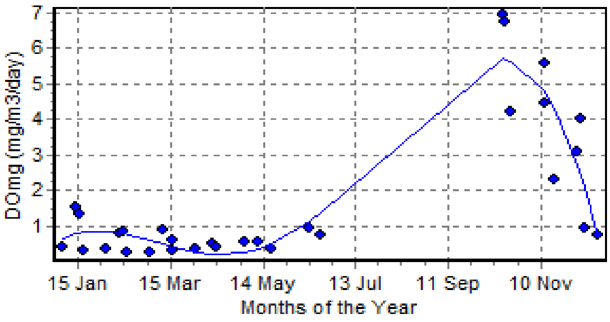

Figure 5.12 Lake Johnson: Hypolimnetic DO plotted against month of year with no regard for year of collection

5.12 Percent Annual Change: Results

The PAC values are calculated using the annual change values obtained from the slopes of the four key variables (chla, SD, TN and TP) that show significant change. This calculation is described in Appendix 2.

For Lake Johnson, three of the four epilimnion variables showed a trend towards a lower trophic level (SD, TP and TN). All four variables showed significant trends and therefore PAC values could be calculated (Table 5.3).

Table 5.3 PAC results for Lake Johnson

Lake Johnson	Chla (mg/m^3)	SD (m)	TP (mg/m^3)	TN (mg/m^3)
Change - units per year	5.23	-0.98	-21.00	-171.72
Average over period	10.86	3.61	61.94	703.09
Percent Annual Change (%/year)	48.16	27.15	-33.90	-24.42

The decision on whether the lake has changed over the monitoring period is made by looking at the p-value of the PAC average. The PAC value for the three years of monitoring Lake Johnson is 3.40 ± 15.40 % per year with a p-value of 0.84. This indicates that the lake is not changing trophic state (Table 5.4).

Table 5.4 P-value range of PAC average

p-value range	Interpretation
<0.1	definite change
0.1 - 0.2	probable change
0.2 - 0.3	possible change
>0.3	no change

5.13 Trophic Level Index: Results

The TLI values are calculated next. This calculation is described Appendix 2. The annual average values are taken from the three years of data shown in Table 5.5.

Table 5.5 Lake Johnson: Trophic level values derived from the average annual values

Period	Chla (mg/m^3)	SD (m)	TP (mg/m^3)	TN (mg/m^3)
May 2006 - Apr 2007	6.27	5.33	72.56	777.5
May 2007 - Apr 2008	17.97	3.1	84.91	963.64
May 2008 - Apr 2009	17.76	2.58	49.62	642.89
Averages	14.00	3.67	69.03	794.68

The trophic level values for each of the variables and TLI values generated from these numbers are shown in Table 5.6, as are the average TLI values from the two most recent years of data.

Table 5.6 Lake Johnson: Trophic level values derived from the average annual values

Period	TLc	TLs	TLp	TLn	TLI Average
May 2006 - Apr 2007	4.25	3.51	5.65	5.09	4.62
May 2007 - Apr 2008	5.41	4.19	5.85	5.37	5.21
May 2008 - Apr 2009	5.39	4.41	5.17	4.84	4.95
Averages	5.02	4.04	5.56	5.10	4.93

The TLI has a time trend value of 0.16 ± 0.25 TLI units per year $^{-1}$, which shows a small upwards trend.

Table 5.6 shows how the four key variables influence the TLI. The average TLc, TLp and TLn values fall into the supertrophic category; however, the TLs falls into the mesotrophic category.

The most recent TLI value (2008 to 2009) for Lake Johnson is 4.93 TLI units, which classifies the lake as eutrophic; although this result is very close to the boundary of supertrophic, which has a TLI value of 5.0 TLI units.

5.14 Plots of other data (NNN, NH4, DRP, pH, turbidity)

Several variables other than those termed key variables were monitored as part of the programme. Figures 5.13 to 5.21 show plots of nitrite-nitrate nitrogen (NNN), ammoniacal nitrogen (NH4), dissolved reactive phosphorus (DRP), pH and turbidity. For each parameter, seasonal trend results and time trend results are given for both the epilimnion and hypolimnion.

Epilimnetic NNN is shown in Figure 5.13A. This is strongly seasonal, with peak values occurring between September and November. This is in contrast to the hypolimnetic NNN (Figure 5.13B), which shows maximum values occurring between January and March, before the thermocline breaks down. The epilimnetic NNN shows a significant downward trend of -1.28 mg m^{-3} $year^{-1}$ (Figure 5.14).

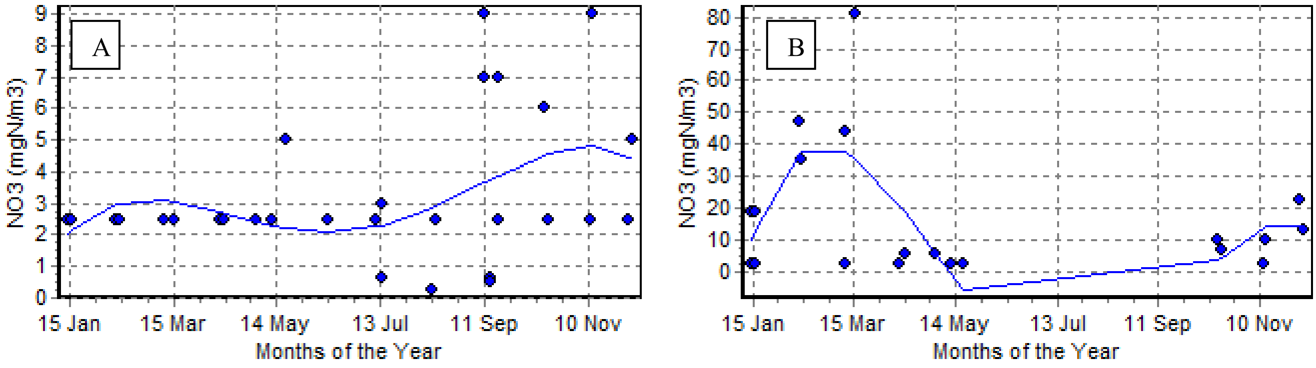

Figure 5.13 Lake Johnson: Plot of annualised nitrite-nitrate nitrogen (A = epilimnion, B= hypolimnion)

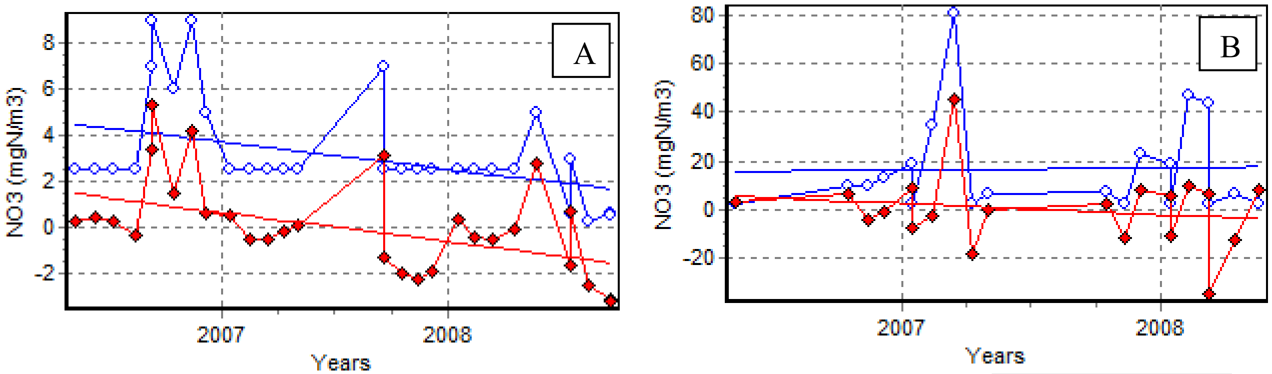

Figure 5.14 Lake Johnson: Plot of observed and deseasonalised time trends for nitrite-nitrate nitrogen (A = epilimnion, B= hypolimnion)

Observed data ---
Deseasonalised ---

NH4 is shown in Figure 5.15. NH4 is most abundant in the epilimnion during late winter/early spring and is released from the sediments during anoxic conditions in the summer months. The epilimnetic NH4 shows a significant downward trend of -41.73 mg m^{-3} year^{-1} (Figure 5.16).

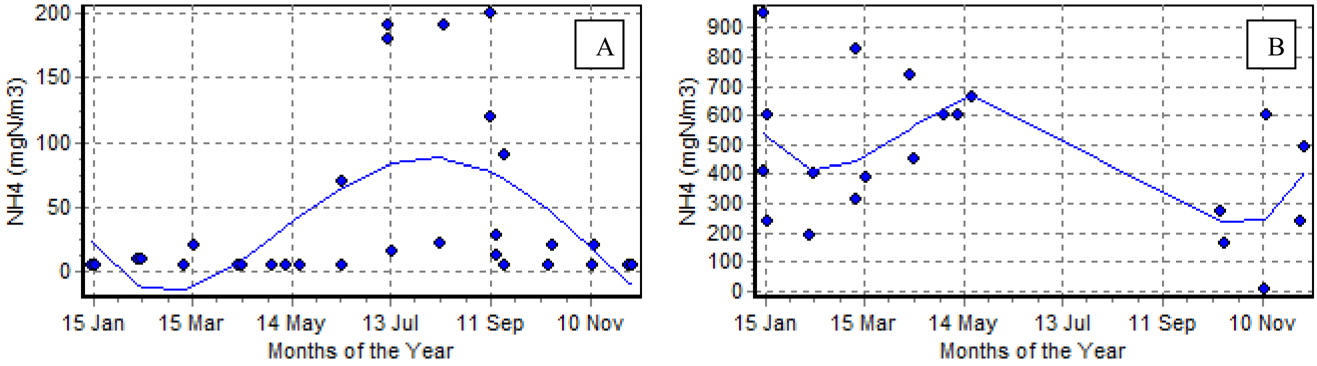

Figure 5.15 **Lake Johnson: Plot of annualised ammoniacal nitrogen (A = epilimnion, B= hypolimnion)**

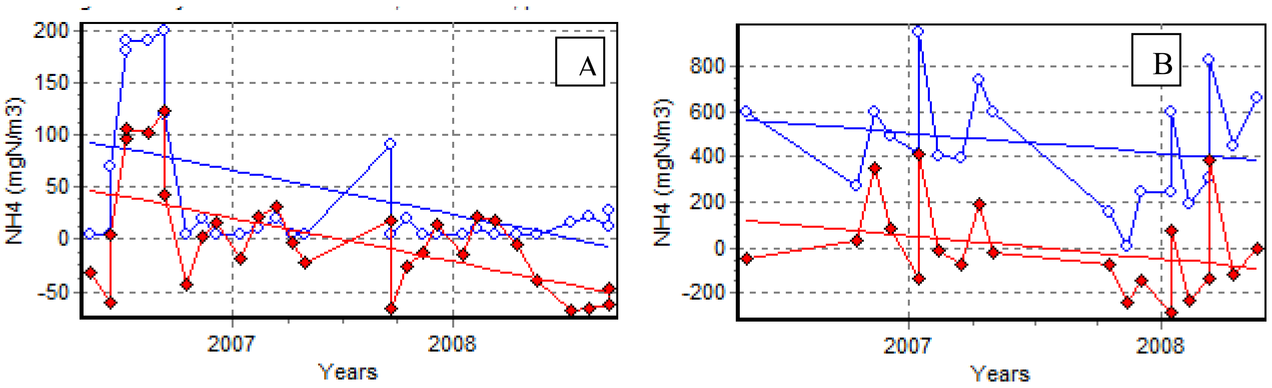

Figure 5.16 **Lake Johnson: Plot of observed and deseasonalised time trends for ammoniacal nitrogen (A = epilimnion, B= hypolimnion)**

Observed data ---
Deseasonalised ---

Eplimnetic DRP is shown in Figure 5.17. It shows a strongly seasonal pattern, with higher values occurring during the winter months. Hypolimnetic DRP also shows a strongly seasonal pattern, with concentrations increasing from November throughout summer, then decreasing rapidly in May when the thermocline breaks down. Epilimnetic DRP also has a significant decline of -16.3 mg m^{-3} year^{-1} (Figure 5.18), which is about 80% of the significant decline observed in TP in Figure 5.4 (-21 mg m^{-3} year^{-1}), indicating that much of the decline in TP is probably due to a decline in DRP.

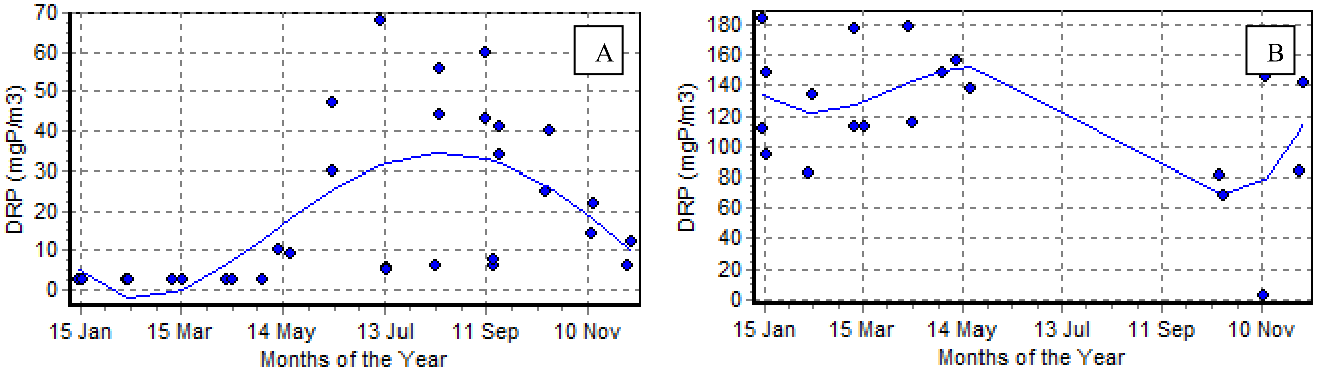

Figure 5.17 **Lake Johnson: Plot of annualised dissolved reactive phosphorus (A = epilimnion, B= hypolimnion)**

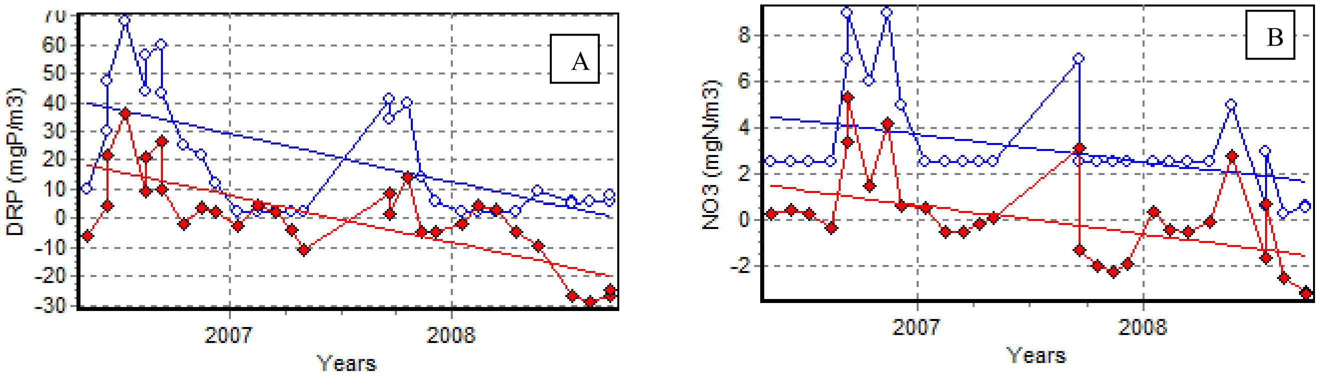

Figure 5.18 **Lake Johnson: Plot of observed and deseasonalised time trends for dissolved reactive phosphorus (A = epilimnion, B= hypolimnion)**

Observed data ---
Deseasonalised ---

Figure 5.19 shows the epilimnetic and hypolimnetic pH conditions. Both show seasonal trends, the epilimnetic pH declining when the lower pH hypolimnetic waters mix upwards and the hypolimnetic pH declining as the hypolimnetic DO is converted into CO_2. Neither showed a trend with time.

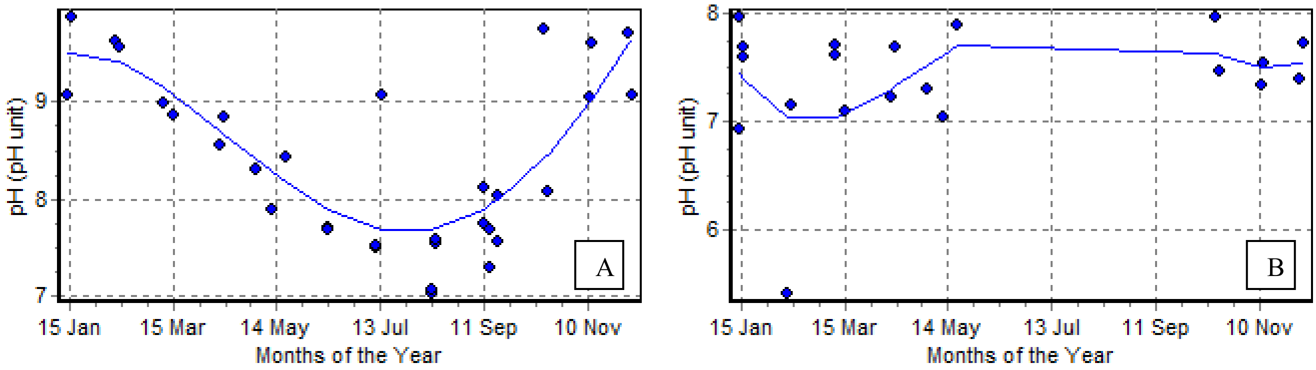

Figure 5.19 **Lake Johnson: Plot of annualised pH (A = epilimnion, B= hypolimnion)**

Figure 5.20A shows the epilimnetic turbidity plot. Turbidity shows a strongly seasonal pattern, with high values occurring in the epilimnion during the summer months. This coincides with high algal biomass values as shown in Figure 5.2. There is an upward trend in epilimnetic turbidity (p-value of <0.05), as shown in Figure 5.20B. This corresponds to an increase in algal biomass and a decrease in clarity.

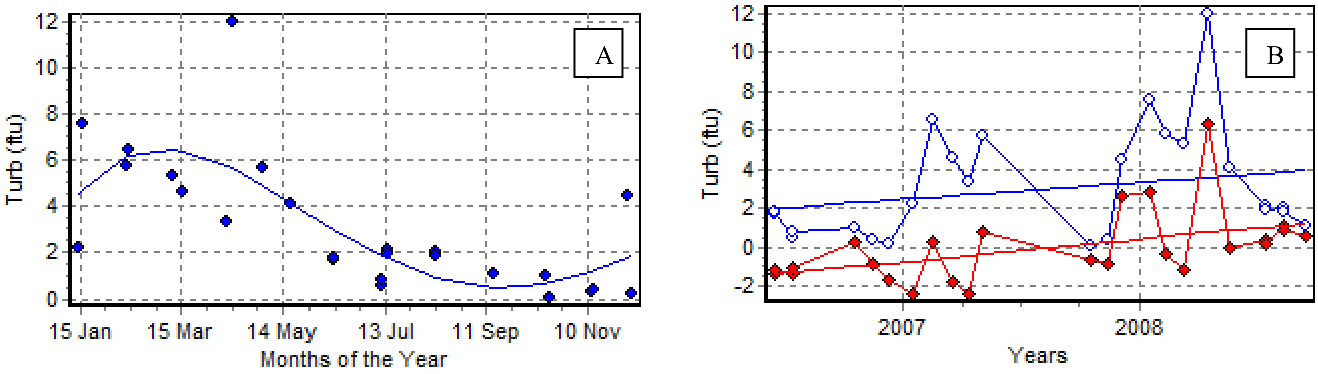

Figure 5.20 Lake Johnson: Epilimnetic turbidity (A = annualised, B= time trend)

5.15 Discussion

Lake Johnson is eutrophic and shows strong thermal stratification accompanied by hypolimnetic anoxia in summer. The lake is unusual in developing an additional anoxic layer in the metalimnion in the summer (Mitchell and Burns, 1979).

Several factors probably contribute to the prolonged stratification: the lake is relatively small and so responds rapidly to variations in temperature; local temperature extremes are greater than in most other areas of New Zealand (Tomlinson, 1976); the lake lies in a steep-sided basin, sheltered from the prevailing winds; and there are no permanent inflows to induce mixing. As a result, the thermocline is shallow and strongly developed. Temperature differences as great as 4.6°C in just 1.9m of water were recorded on 13 February 2007.

In Lake Johnson there are large seasonal changes in oxygen: surface saturations ranged from 66% to 121% and short-lived thermocline maxima as high as 143% were recorded. At 25m, the water was anaerobic for up to seven months.

By January each year, the deepest hypolimnetic water was deoxygenated, so that the lake consists of two anoxic strata and two containing oxygen. Figure 5.21 shows that in January 2008 water in the thermocline became anoxic when the upper hypolimnion still contained up to 4.0 mg/l of oxygen. The thermocline oxygen minimum coincided exactly with the maximum chlorophyll concentration. The hypolimnetic oxygen is generally consumed by April/May.

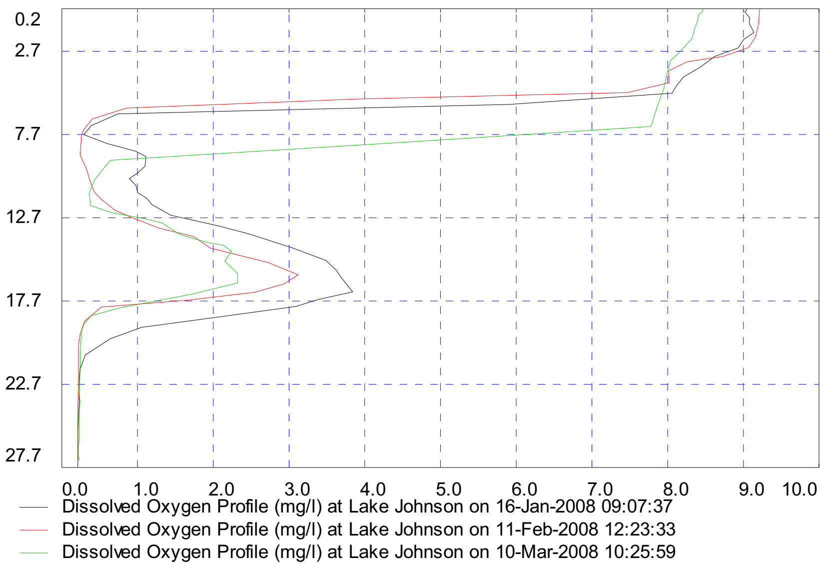

Figure 5.21 **Lake Johnson: Depth profiles for dissolved oxygen (mg/l) January, February and March 2008**

Two factors probably contribute to the development of anoxia in the thermocline. Firstly the lake has an abundance of algae, with chla reaching levels of up to 100 mg/m^3 and secondly thermal stratification is intense, with the probability that large amounts of organic matter settle out of the epilimnion.

The physical stratification of Lake Johnson for seven months of each year into distinct density layers determines much of what happens to algal growth, fisheries habitat and the distribution of nutrients and oxygen within the lake. The stratification seals off the deeper waters from oxygen in the air and, by late January, the hypolimnetic oxygen consumption resulting from respiration causes the oxygen concentration to drop to zero.

This large decline in oxygen concentration restricts fish and other animals to the upper layers of water during much of the summer-autumn period. It is also responsible for the internal release of large concentrations of biologically available phosphorus and nitrogen from the sediments into the hypolimnion. During the summer-autumn stratified period, mixing with the high nutrient waters of the hypolimnion is restricted, but in May when the lake mixes, these nutrients from the deep water are then available for algal growth.

The three-year monitoring programme (2006 to 2009) revealed algal blooms and a deoxygenated hypolimnion. These are the primary symptoms of eutrophication, which are probably directly related to the phosphorus available in the lake (due mainly to agricultural activities of the past).

The phosphorus content of the surface waters decreases as the summer progresses (Figure 5.4), because of its removal by organic material settling out of the epilimnion into the bottom waters. However, when oxygen in the hypolimnion is used up, there is a massive release of phosphorus from the sediments to the overlying waters, giving the high hypolimnetic phosphorus concentrations observed in the hypolimnion in February to May (Figure 5.4). In June the epilimnion cools, the lake waters mix and the lake enters its isothermal phase, which lasts until November.

Thus in June, the concentration of phosphorus in the surface waters increases because of the incorporation of some of the phosphorus previously held only in the bottom waters. As the isothermal period proceeds, the phosphorus concentrations slowly decrease by the settling out of particulate material from the lake waters to the sediments.

The anoxic conditions cause the denitrification of nitrate to ammonia. Ammoniacal nitrogen is also released from the sediments during anoxic conditions (Figure 5.22). In stratified lakes, increasing ammoniacal nitrogen values are often associated with the increasing prevalence of anoxic conditions which are the result of increasing eutrophication.

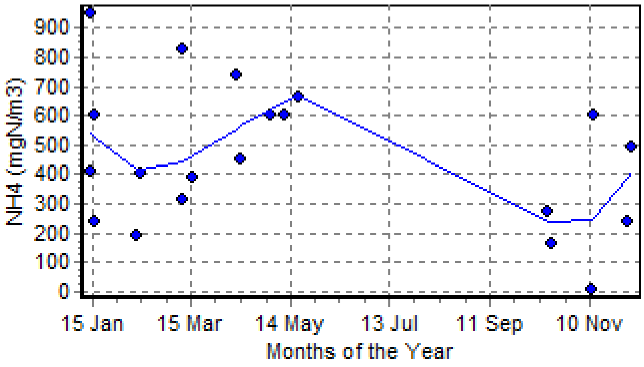

Figure 5.22 Lake Johnson: Hypolimnetic NH_4 plotted against month of year

Ammonia (NH_3) is the main toxic component for aquatic organisms, the prevalence of which is dependent on the pH, temperature and salinity of the water. pH is particularly important in terms of ammoniacal nitrogen toxicity (to fish). Figure 5.23 shows the pH depth profile for January and February 2008. During this time, epilimnion temperatures were in excess of 20°C. This combination of high pH and high temperature meant that ammonia toxicity was also almost certainly present in Lake Johnson.

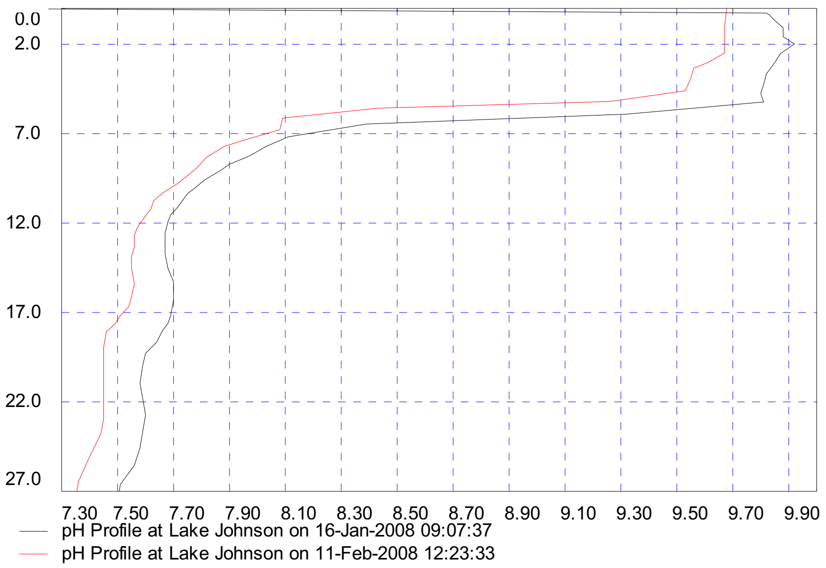

Figure 5.23 Lake Johnson: Depth profile for pH. January and February 2008

It is useful to compare the results of the trophic monitoring undertaken between 2006 and 2009 with the data collected between 1970 and 1972 (Mitchell et al. 1972). However, the only comparable data are chla results; these are given in Table 5.7. Chla concentrations in 1969 to 1971 were at a similar level to those of 2008 and 2009; however, the summer of 2007 had much lower chla concentrations.

Table 5.7 TLI values for Lake Johnson for two time periods: 1970 to 1972 and 2006 to 2009

Period	Chla mg m^{-3}	Average chla mg m^{-3}
09/1969 to 08/1970	19.13	18.61
09/1970 to 08/1971	18.09	
05/2006 to 04/2007	6.27	14.00
05/2007 to 04/2008	17.9	
05/2008 to 04/2009	17.7	

Average levels of algal concentrations are indicative of a supertrophic state in both time periods.

Average PAC values during the 2006 to 2009 monitoring period indicate that there has been no change in lake water quality since 2006. In the 2006 to 2009 period, levels of chla, TN and TP fall into the supertrophic category, and SD falls into the mesotrophic category. TLI values do not show any significant improvement or degradation over the three years, and there is no indication of a shift in trophic status. Overall lake water quality is classified as eutrophic, although the lake is extremely close to being classified as supertrophic.

There is a trend of decreasing nitrogen of 171 mg m^{-3} year^{-1}, and decreasing TP concentrations of 21 mg m^{-3} year^{-1}; however start-off levels were so high that even if the trend continues at this rate, there is unlikely to be a drop in chla concentrations for at least five years. At the moment these significant decreases are not having an effect on SD or chla concentrations. A trend of decreasing SD of 0.98 m year^{-1} indicates a decrease in water clarity and there was a corresponding significant increase in chla concentrations (5.23 mg m^{-3} year^{-1}).

Analysis of the following variables failed to find any significant trends: pH, turbidity, nitrate and dissolved reactive phosphorus. A lack of trends in these variables and any strong trends in the key variables may indicate that the lake is in a relatively stable state.

5.16 Conclusion

Lake Johnson is a small, relatively shallow, nutrient-rich lake that has likely undergone progressive eutrophication since catchment development and intensification began. The monitoring between 2006 and 2009 shows that, while the lake appears to be in a relatively stable state, there has been a significant decrease in TP and TN occurring over the last three years. It can currently be classified as being in a eutrophic state, although three of the TLI variables (TLp, TLn and TLc) fall into the supertrophic category.

6. Lake Onslow

6.1 General description

Lake Onslow is set in wide open Otago tussock 700m above sea level. It is situated about 22km east of Roxburgh, at the northwest end of the Lammerlaw Range. The catchment of Lake Onslow has an area of 126 km^2 and is used predominantly for grazing. Figure 6.1 gives general lake characteristics as well as land use type in the catchment.

Lake characteristics	
Lake type	Dammed
Lake area (km^2)	3.8
Inlet	Fortification Ck Teviot North
Outlet	Teviot South Boundary Ck
Max depth (m)	9.5
Catchment area (km^2)	126
Land use % of Total	
Built-up area	0.01
Herbaceous freshwater veg.	5.71
Lake and pond	6.10
Short rotation cropland	1.84
Tall Tussock grassland	86.34

Figure 6.1 **Lake Onslow: Physical characteristics and catchment land use**

(source: www.nzfishing.com)

Lake Onslow has a significant number of natural values, including significant trout spawning and a significant presence of trout. For this reason, it is listed in the Water Plan. Cultural values associated with food gathering and processing (mahika kai) and the recognition of the lake as a treasured resource (waahi taoka) have been identified as important in Lake Onslow. These cultural values are listed in the Water Plan. Water quality has a major impact on these values.

In the past five years there has been some land use modification in the catchment, with tussock being replaced by pasture. This activity and associated implications in terms of more intensive agricultural methods may have an impact on future water quality.

6.2 Lake Onslow: History

In 1888, the Roxburgh Amalgamated Mining Company constructed an 18ft high rock dam on the Upper Teviot River, flooding an area called Dismal Swamp. The resulting lake was named after a Governor of New Zealand, William Hillier, Fourth Earl of Onslow.

Originally built as a water supply for gold mining and irrigation purposes, in 1924 the dam started operating as an irrigation power scheme. Between 1888 and 1938 the dam was raised three times. In 1982 a new dam was built just downstream of the original structure and this increased the area of the lake from 367ha to about 830ha.

The Teviot scheme, run by Pioneer Generation Ltd, has five Teviot River stations originating from Lake Onslow. The lake has a storage capacity of 46,491,079m³, with an operating head of 9.5m. It has an output of 1.8kW.

6.3 Lake Onslow: Results

As discussed in section 3, the key variables used to determine the trophic level of a lake are algal biomass, clarity and nutrient concentrations. The results are based on monitoring undertaken from May 2004 to April 2009. This longer time frame is due to a less frequent monitoring programme for the lake. Secchi depth was not taken at Lake Onslow as the lake is naturally tannic and will always have limited clarity, and the sampling location had limited depth.

This section details results as follows:

- Seasonal trends for algal biomass and nutrients in the epilimnion
- Deseasonalised data and trends for algal biomass and nutrients in the epilimnion

Figures 6.2 to 6.4 show that while there is some scatter in all variables with time of year, seasonal trends are apparent.

6.4 Algal Biomass (chla)

Figure 6.2 shows that concentrations of algal biomass in the epilimnion change little from March to October, but during the summer months concentrations increase slightly; however, the concentrations are never very high.

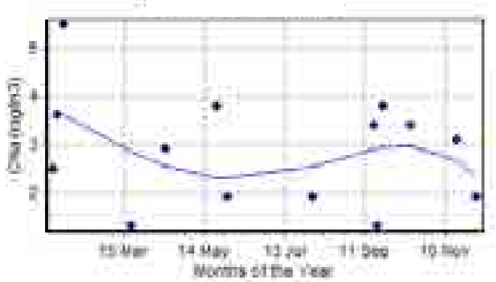

Figure 6.2 Lake Onslow: Chla plotted against month of year

6.5 Nutrients (total phosphorus and total nitrogen)

Figure 6.3 shows that TP exhibits slight seasonal patterns, with higher values found in the summer months. TP values did not change over the monitoring period.

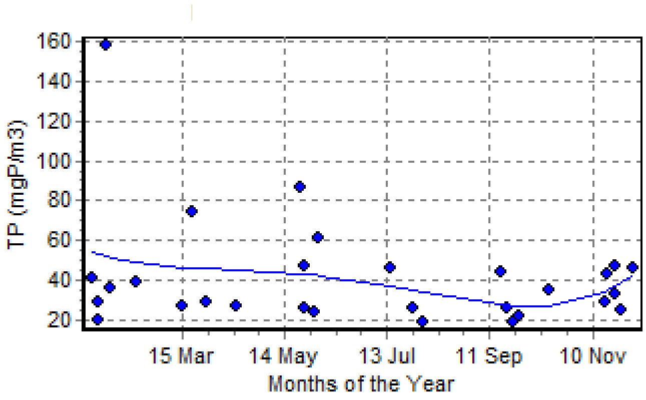

Figure 6.3 **Lake Onslow: Total phosphorus plotted against month of year**

Figure 6.4 shows a seasonal pattern, with higher concentrations of TN found in the summer months.

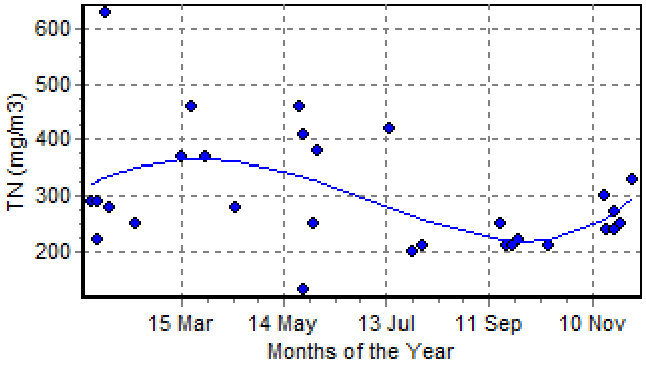

Figure 6.4 **Lake Onslow: Total nitrogen plotted against month of year**

Figures 6.5 to 6.7 show plots of deseasonalised data over time and any trends in the three years of data.

6.6 Algal biomass (chla) time trend

Figure 6.5 shows the plot of deseasonalised chla data over time. Chla increased by 0.29 mg m^{-3}year^{-1}, but the trend was not significant.

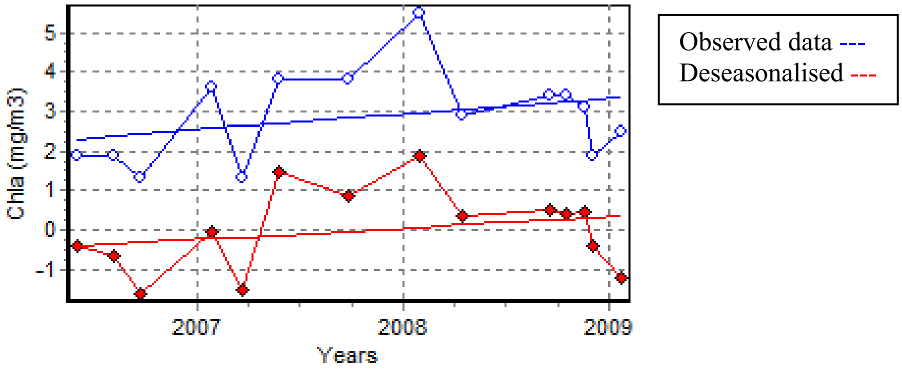

Figure 6.5 **Lake Onslow: Plot of observed and deseasonalised time trends for chla**

6.7 Nutrients (total phosphorus and total nitrogen) time trend

Figure 6.6 shows the plots of deseasonalised TP data over time. TP increased by 4.7 mg m^{-3} year^{-1}, but the trend was not significant.

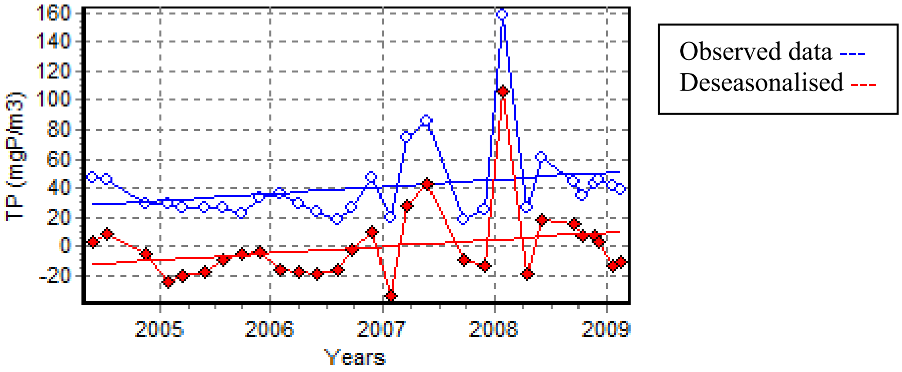

Figure 6.6 **Lake Onslow: Plot of observed and deseasonalised time trends for total phosphorus**

Figure 6.7 shows the plot of deseasonalised TN data over time. TN increased by 1.44 mg m^{-3} year^{-1}, but the trend was not significant.

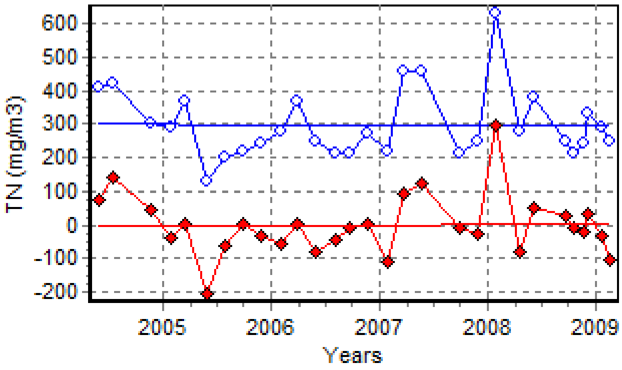

Figure 6.7 **Lake Onslow: Plot of observed and deseasonalised time trends for total nitrogen**

6.8 Percent Annual Change (PAC): Results

The PAC values are calculated using the annual change values obtained from the slopes of the three key variables (chla, TN and TP) that show significant change. This calculation is described in Appendix 2.

For Lake Onslow, all the variables showed a non-significant trend towards a higher trophic level; however, only PAC values calculated from significant trend lines are considered indicative of change in a particular variable. All three variables have non-significant slopes and thus the PAC values for the three variables were replaced by a value of 0.00 (Table 6.1).

Table 6.1 **PAC results for Lake Onslow**

Lake Onslow	**Chla (mg/m^3)**	**TP (mg/m^3)**	**TN (mg/m^3)**
Change - units per year	(0.29)	(4.67)	(1.44)
Average over period	(2.88)	(40.83)	(297.59)
Percent Annual Change (%/year)	0.00	0.00	0.00

As Lake Onslow had no significant trend lines and all PAC values were replaced by 0.00, the average PAC value for the three years of monitoring Lake Johnson was 0.00% year^{-1} with a p-value of 1.00, which suggests that the lake did not change over the monitoring period (Table 6.2).

Table 6.2 **P-value range of PAC average**

p-value range	**Interpretation**
<0.1	definite change
0.1 - 0.2	probable change
0.2 - 0.3	possible change
>0.3	no change

6.9 Trophic Level Index Results

The TLI values are calculated next. This calculation is described in Appendix 2. The annual average values are taken from the three years of data shown in Table 6.3.

Table 6.3 Lake Onslow: Average annual values for the three key variables

Period	Chla (mg/m^3)	TP (mg/m^3)	TN (mg/m^3)
May 2004 - Apr 2005		35.6	358
May 2005 - Apr 2006		28.67	240
May 2006 - Apr 2007	2	35	270
May 2007 - Apr 2008	4	63	366
May 2008 - Apr 2009	2.86	44.14	278.57
Averages	2.95	41.28	302.51

The trophic level values for each variable and TLI values generated from these numbers are shown in Table 6.4, as are the average TLI values from the two most recent years of data.

Table 6.4 Lake Onslow: Trophic level values derived from the average annual values

Period	TLc	TLp	TLn	TLI Average
May 2004 - Apr 2005		4.75	4.08	4.41
May 2005 - Apr 2006		4.47	3.55	4.01
May 2006 - Apr 2007	2.98	4.73	3.71	3.81
May 2007 - Apr 2008	3.75	5.47	4.11	4.44
May 2008 - Apr 2009	3.38	5.02	3.75	4.05
Averages	3.37	4.89	3.84	4.13

The TLI has a time trend value of -0.02 ± 0.15 TLI units per year $^{-1}$, which shows a small downwards trend.

Table 6.4 shows how the four key variables influence the TLI. The average TLc and TLn values fall into the mesotrophic category; however, TLp value falls into the eutrophic category. The most recent TLI value (2008 to 2009) for Lake Onslow is 4.13 TLI units, which classifies the lake as eutrophic.

6.10 Plots of other data (NNN, NH4, DRP, pH, turbidity and DO)

Several variables other than those termed key variables were monitored as part of the programme. Figures 6.8 to 6.14 show plots of nitrite-nitrate nitrogen (NNN), ammoniacal nitrogen (NH4), dissolved reactive phosphorus (DRP), pH, turbidity and dissolved oxygen (DO). For each parameter seasonal trend results are given. If any of the parameters show a significant trend over time then these plots are also shown.

NNN is shown in Figure 6.8. This is weakly seasonal, with peak values occurring between May and August. This does not show any trend of change with time.

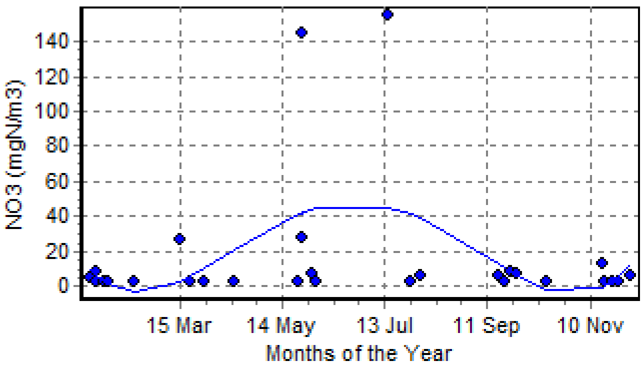

Figure 6.8 Lake Onslow: Plot of annualised nitrite-nitrate nitrogen

Figure 6.9 shows that even though NH4 increases over the summer months, concentrations are low and not indicative of anoxic conditions which cause the denitrification of nitrate to ammonia.

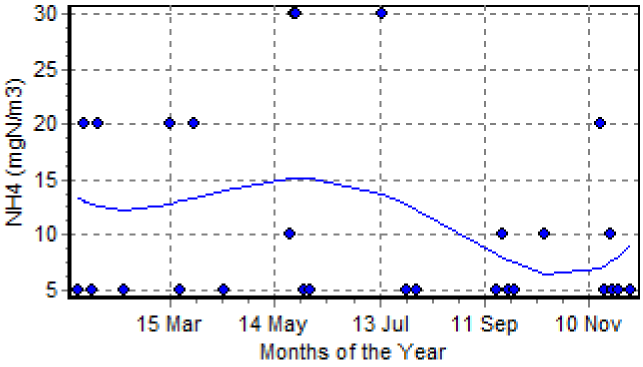

Figure 6.9 Lake Onslow: Plot of annualised NH4

Figure 6.10 shows the annualised data for DRP. It shows that the DRP content of the surface waters decreases from October and, as summer progresses, this is likely to be due to its removal by algae. The decrease in TP observed (Figure 6.3) is likely to be due to the settling out of particulate material from the lake waters to the sediments. DRP also has a non-significant increase of 0.79 mg P m^{-3} year, which is about a sixth of the non-significant increase observed in TP in Figure 6.3 (4.6 mg P m^{-3}), indicating that much of the increase in TP is not biologically available.

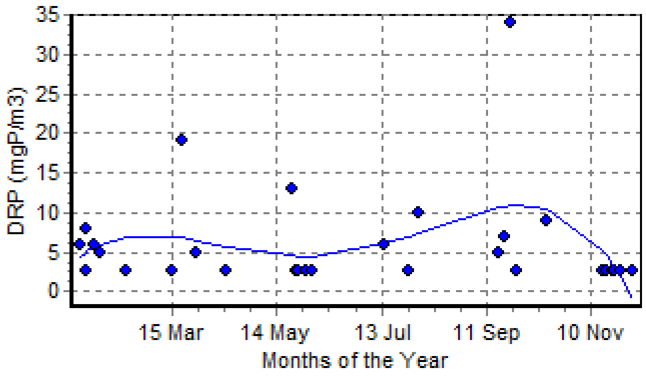

Figure 6.10 Lake Onslow: Plot of annualised DRP

Figure 6.11 shows the pH conditions. There is a seasonal trend; the epilimnetic pH increases in the summer months, probably as a result of some algal growth.

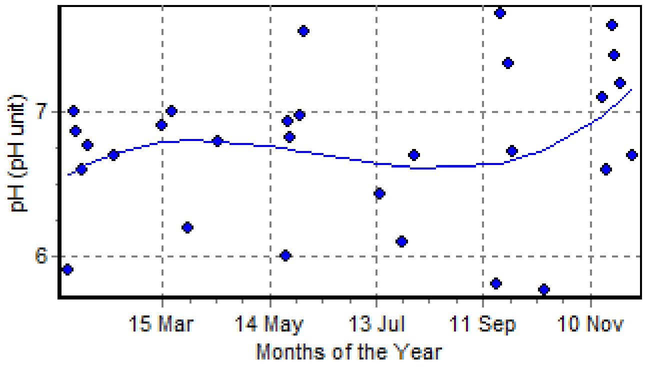

Figure 6.11 Lake Onslow: Plot of annualised pH

The turbidity plot does not show a strongly seasonal pattern. However, Figure 6.12 shows that turbidity is increasing at 1.001 NTU m^{-3} year, and Figure 6.13 shows that the trend was significant (p=<0.05).

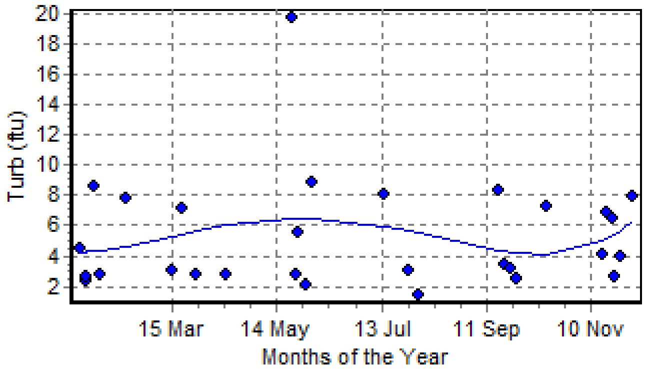

Figure 6.12 Lake Onslow: Plot of annualised turbidity

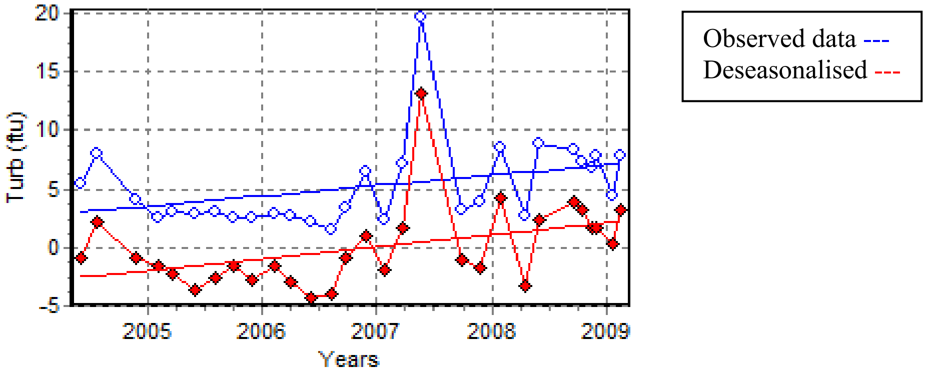

Figure 6.13 Lake Onslow: Plot of turbidity time trend

Figure 6.14 shows that the dissolved oxygen concentrations are at their highest in autumn and winter. The low concentration of algae found in the lake means that there is no summer peak associated with algal blooms.

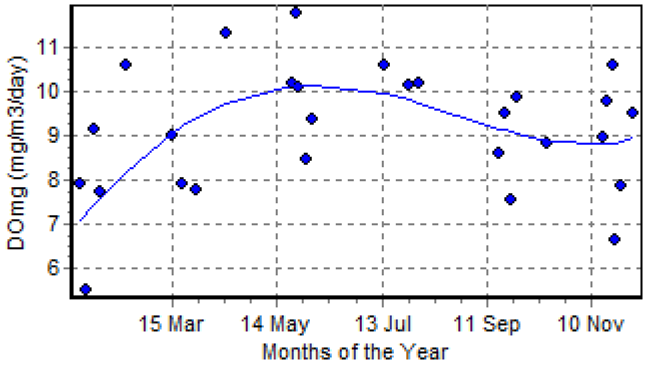

Figure 6.14 Lake Onslow: Plot of annualised dissolved oxygen

6.11 Discussion

Lake Onslow was included in the monitoring programme because there was concern over changing land use around the lake margins. Tussock has been removed and pasture has increased. Recent monitoring has shown more fluctuation in levels of phosphorus and nitrogen, which could be an indication that this changing land use is having an adverse effect on the lake's water quality.

Although the trophic level is not changing, the lake has surprisingly high concentrations of phosphorus. Average levels of TN and chla are indicative of a mesotrophic state whereas levels of TP fall into the eutrophic category. Overall, lake water quality is classified as eutrophic.

Trends of the concentrations of all the key variables (chla, TN and TP) have p-values of >0.05 and, therefore, the apparent increasing trends are not significant. Average PAC values during this monitoring period indicate that there has been no change in lake water quality.

TLI values show little change since 2005, and there is no upwards trend in trophic state. Relatively low nitrogen levels are likely to be exhibiting control over the algal biomass. With increasing nitrogen concentrations, it is likely that chla will increase.

No significant trends were found when data for NNN, NH4, DRP, pH, DO were analysed; however, turbidity did show a significant increase.

6.12 Conclusion

Lake Onslow is a man-made, relatively shallow lake in an undeveloped high country catchment. However, in the last few years there has been some land use change in the lake's immediate catchment from tussock to pasture. As a water body's trophic state is largely determined by nutrient inputs from the surrounding catchment (Barnes, 2002), there is the possibility that the trophic state of Lake Onslow may change with agricultural intensification.

The lake can currently be classified as being in an eutrophic state. The average TLn and TLc values fall into the mesotrophic category, however, the TLp value falls into the eutrophic category; this is most likely due to the shallowness of the lake at the monitoring point and the suspension of organic matter in the water column.

There were no increasing trends found in the key variables (chla, TN and TP) during the monitoring between 2006 and 2009, suggesting that the lake is in a relatively stable state.

7. Lake Wakatipu

7.1 General description

The second largest of the southern glacial lakes, Lake Wakatipu is 75.2km long and up to 5km wide, and covers an area of 289km^2. The lake is 310m above sea level, is up to 380m deep, and occupies a single elongated glacial trench which has a gently sloping flat floor. Figure 7.1 gives general lake characteristics.

The Dart and Rees Rivers flow into the northern end. The lake then runs south for 30km before turning abruptly to the east. Twenty kilometres further along, it turns sharply to the south, reaching its southern end 30km further south, near Kingston. The lake is drained by the Kawarau River, which flows out from the lake's Frankton Arm, 8km east of Queenstown. At the foot of the lake is a natural dam of moraine.

Lake characteristics	
Lake type	Glacial
Lake area (km^2)	289
Inlet	Dart, Rees
Outlet	Kawarau
Max depth (m)	380
Catchment area (km^2)	2674

Figure 7.1 Lake Wakatipu: Physical characteristics

(source: www.nzfishing.com)

Lake Wakatipu has a standing wave or seiche. Water in the lake is set in oscillation by wind and atmospheric pressure variation. The oscillation has definite periods due to the depth and cross-sectional area of the lake. The oscillations in Lake Wakatipu have periods near 52.0, 26.7, 18.5, 15.0 and 10.0 min. The most energetic mode has a period of 26.7 min (Bottomley G.A., 1955).

Relatively few studies have been carried out on Lake Wakatipu. Schallenberg et al. 1999 assembled published and unpublished data on trophic state variables measured in Lake Wakatipu from 1952 onwards. These are presented in Appendix 3.

Lake Wakatipu has a number of natural values, including significant presence of trout and salmon. It is an outstanding natural feature for many reasons (listed in the Water Plan). Cultural values associated with food gathering and processing (mahika kai), the protection of nursery and breeding areas for native fish and birds (kohanga) and the recognition of the lake as a treasured resource (waahi taoka) have been identified as important in Lake Wakatipu. These and other cultural values are listed in the Water Plan. Water quality has a major impact on these values.

There are no large consented discharges into Lake Wakatipu, but residential and commercial development is changing the nature of the catchment, which may have an impact on future water quality.

7.2 Location and land use

Lake Wakatipu is of typical glacial origin; a large delta occupies the head of the lake where the Dart and Rees Rivers enter.

Lake Wakatipu is bordered on all sides by glaciated mountains, the highest of which is Mount Earnslaw near the head of the lake. Lake Wakatipu has a barren appearance because of the lack of forest throughout most of its 2674 km^2 catchment area.

Settlements around the lake shore include Queenstown and the villages of Kingston and Glenorchy. A number of large sheep stations lie around the lake shores, including Mount Nicholas and Walter Peak. The only parts of the lake shores that can be reached easily from public roads are around Queenstown and on the road to Glenorchy at the north end of the lake.

Figure 7.1 gives land use type in the catchment. The catchment is dominated by tall tussock grassland, indigenous forest and alpine gravel and rock.

Table 7.1 Lake Wakatipu: Catchment land use

Land use % of total			
Alpine grass/herbfield	0.75	Lake and pond	7.98
Alpine gravel and rock	6.55	Low prod. grassland	6.33
Broadleaved indig. hardwoods	0.67	Manuka and kanuka	1.54
Built-up area	0.16	Permanent snow/ice	1.64
Deciduous hardwoods	0.15	River/lakeshore gravel/rocks	1.59
Fernland	5.46	Sub alpine shrubland	4.16
High prod. exotic grass	4.81	Tall tussock grassland	41.12
Indigenous forest	15.86	Other	1.23

7.3 Lake Wakatipu: Results

Lake Wakatipu had three monitoring stations located at Queesntown Bay, Frankton Arm and an open water site (Figure 7.2). The three stations enabled any spatial variation in water quality to be determined.

Figure 7.2 Water quality monitoring sites on Lake Wakatipu

As discussed in section 3, the key variables used to determine the trophic level of a lake are algal biomass, clarity and nutrient concentrations. Between 2006 and 2009, ORC monitored these parameters at the three sites in Lake Wakatipu.

This section details results as follows:

- Seasonal trends for algal biomass, clarity and nutrients in the epilimnion
- Deseasonalised data and trends for algal biomass, clarity and nutrients in the epilimnion

7.4 Algal biomass (chla)

In Frankton Arm and Queenstown Bay, algal biomass is at its lowest in early summer, before beginning to climb in late autumn. The open water site has maximum concentrations in early summer (Figure 7.3).

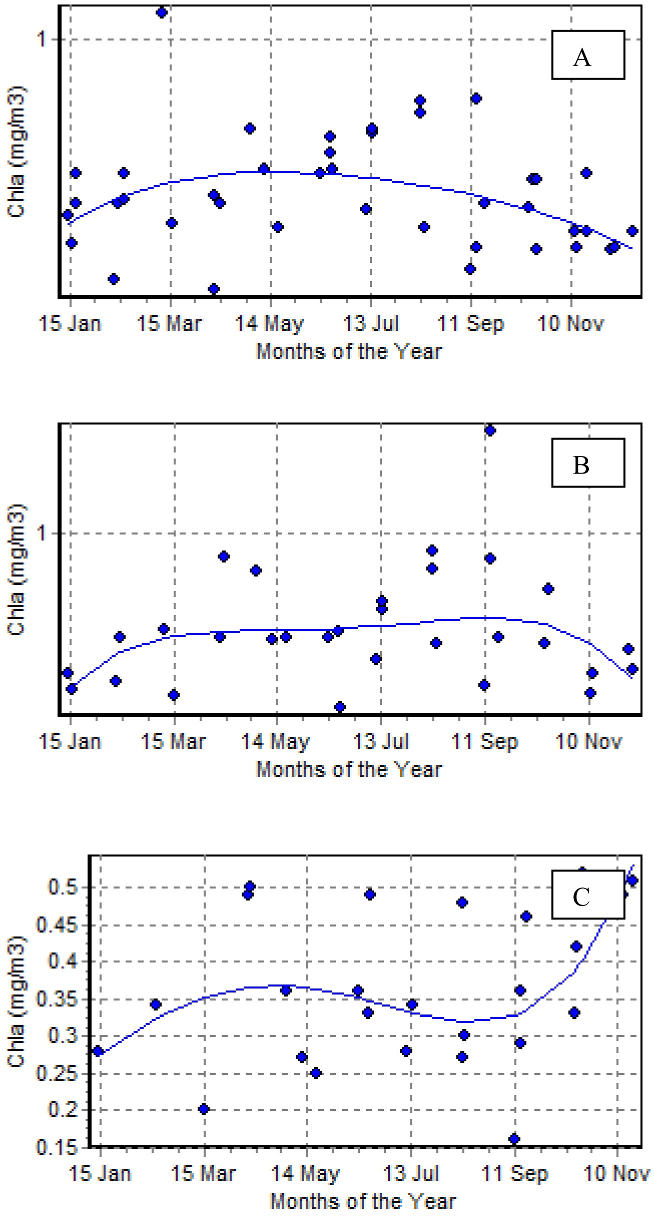

Figure 7.3 **Lake Wakatipu: Chla plotted against month of year (A=Frankton Arm, B=Queenstown Bay, C=open water)**

7.5 Clarity (secchi depth)

Figure 7.4 shows that clarity was seasonal in pattern at all sites. During the summer months clarity was lowest at all sites. The greatest clarity varied between sites; Frankton Arm and the open water site recorded greatest clarity in winter, but Frankton Arm recorded greater clarity in spring. Depths varied significantly from year to year.

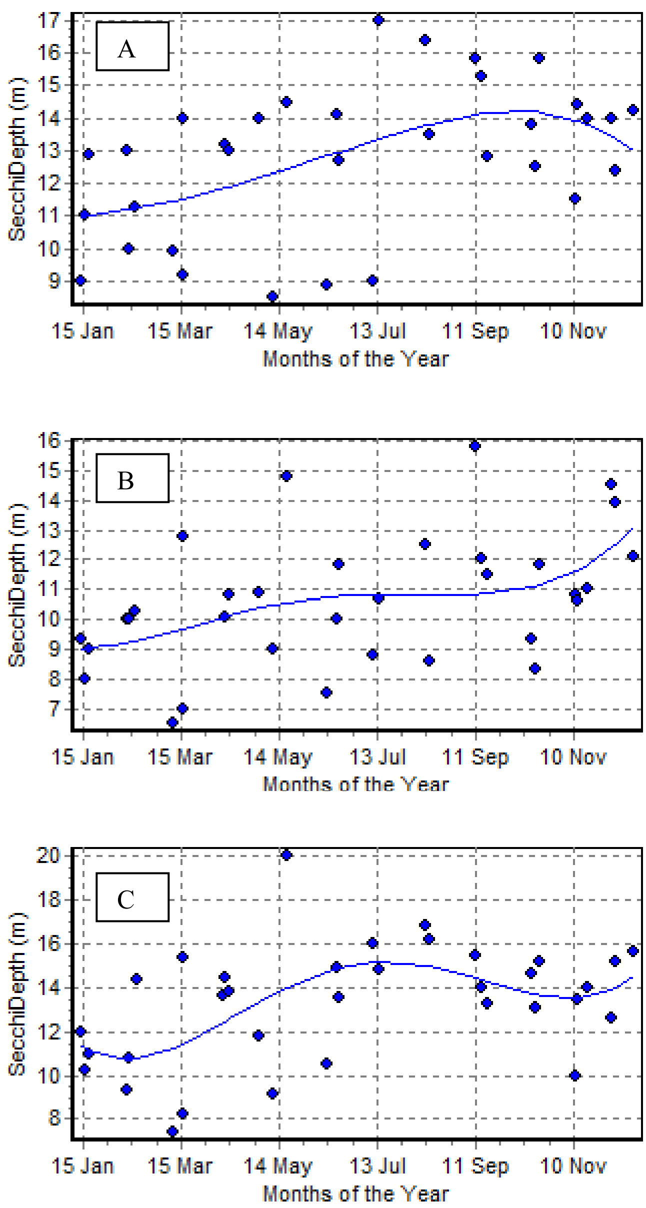

Figure 7.4 **Lake Wakatipu: Secchi depth plotted against month of year A=Frankton Arm, B=Queenstown Bay, C=open water)**

7.6 Nutrients (total phosphorus and total nitrogen)

Epilimnetic TP concentrations remain fairly constant for most of the year, but each site shows a decrease in TP concentrations during the spring (Figure 7.5).

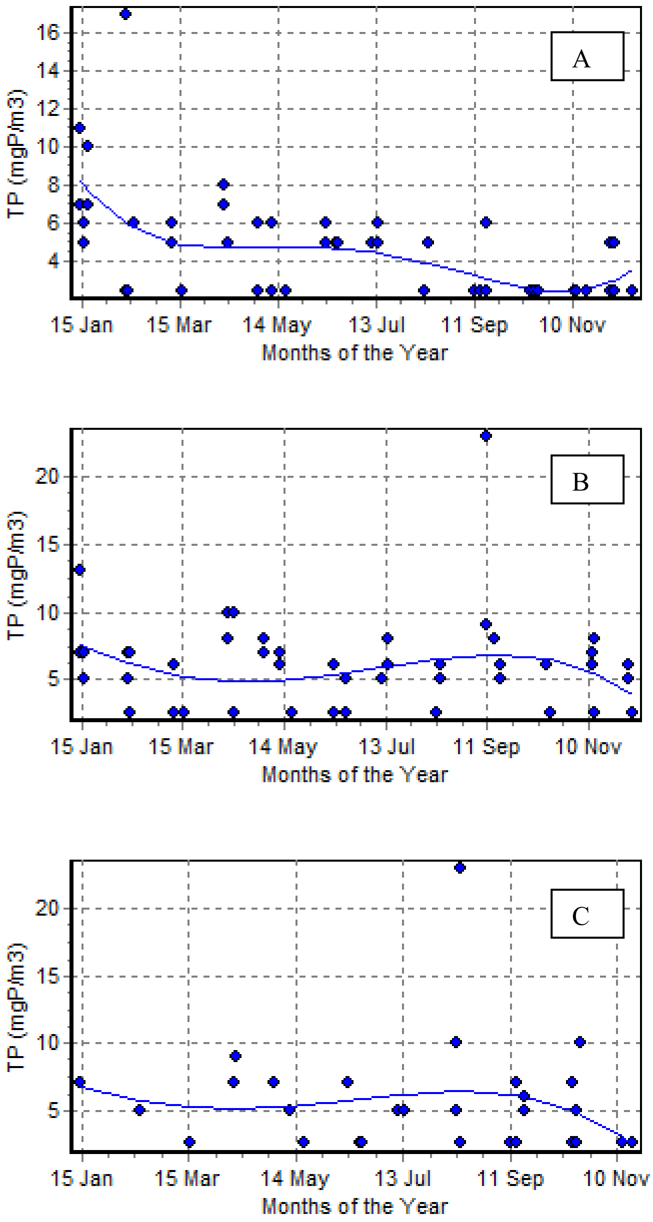

Figure 7.5 **Lake Wakatipu: Epilimnetic total phosphorus plotted against month of year. (A=Frankton Arm, B=Queenstown Bay, C=open water)**

Epilimnetic TN shows a lot of scatter at all sites. In Queenstown Bay and the open water site TN shows a bimodal pattern with peaks in summer and autumn. Frankton Arm does not show this pattern (Figure 7.6).

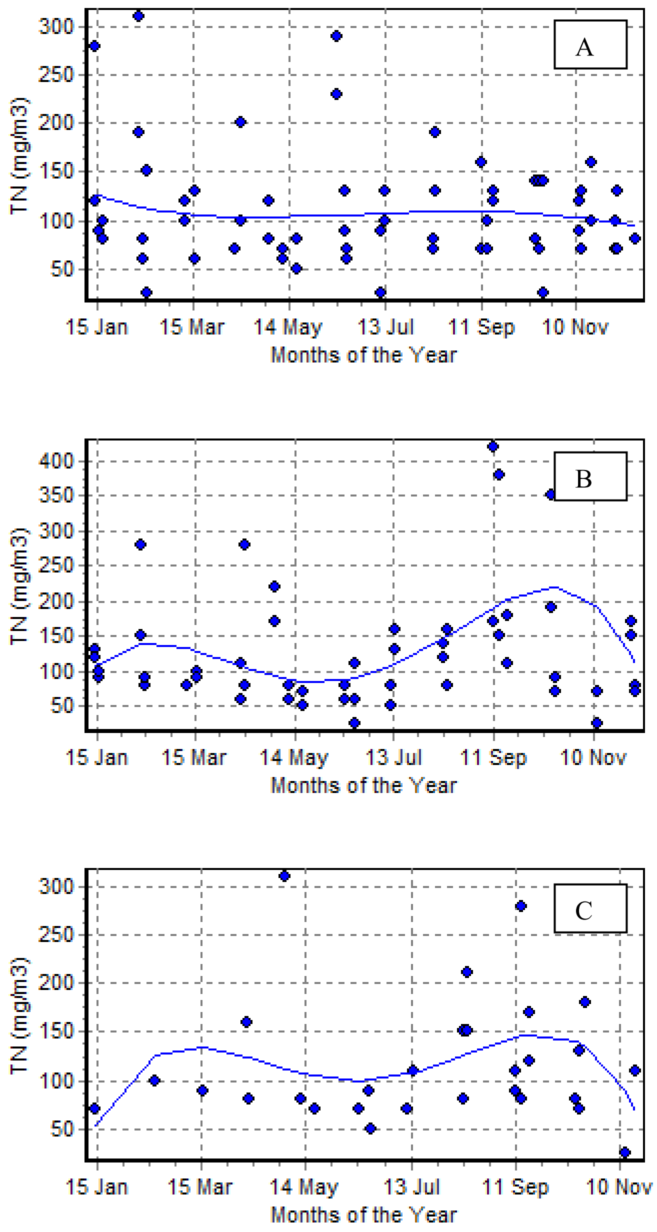

Figure 7.6 **Lake Wakatipu: Epilimnetic total nitrogen plotted against month of year (A=Frankton Arm, B=Queenstown Bay, C=open water)**

Figures 7.7 to 7.10 show plots of deseasonalised data over time and any trends in the three years of data.

7.7 Algal biomass (chla) time trend

Figure 7.7 shows that two sites show a significant ($p < 0.05$) increase in algae concentrations over the monitoring period; only the open water site did not show any significant increase. Frankton Arm increased by 0.07 mg m^{-3} $year^{-1}$ and Queenstown Bay by 0.16 mg m^{-3} $year^{-1}$.

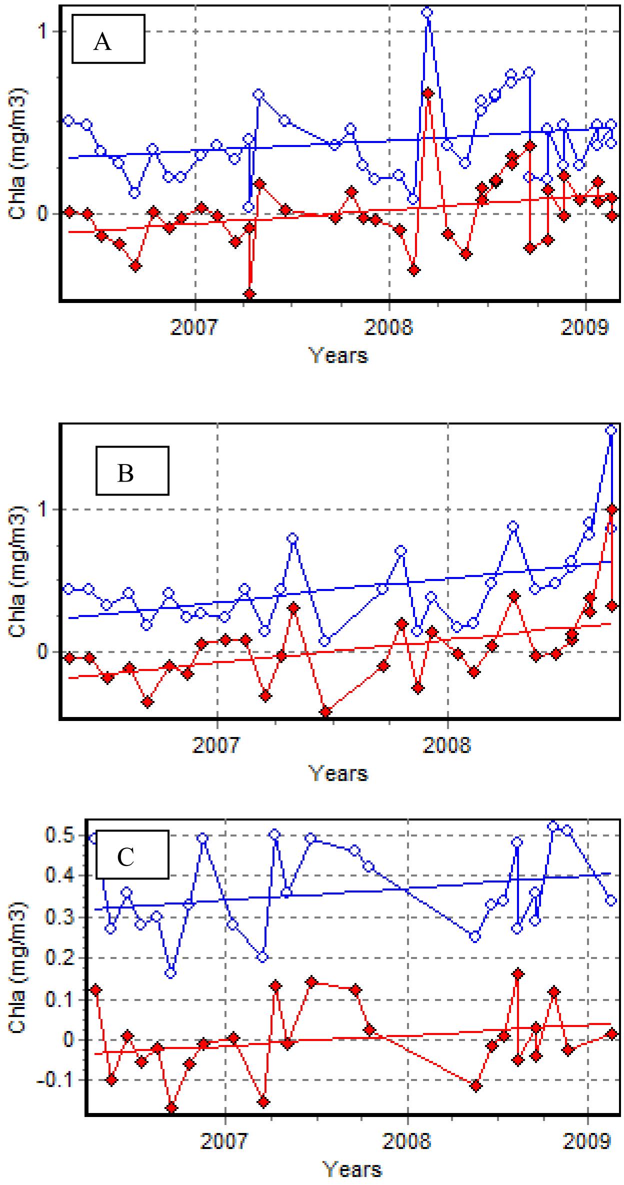

Figure 7.7 Lake Wakatipu: Plot of observed and deseasonalised time trends for chla (A=Frankton Arm, B=Queenstown Bay, C=open water)

7.8 Clarity (secchi depth) time trend

Figure 7.8 shows a significant trend ($p < 0.05$) of SD in the Frankton Arm (increasing by 1.41m year^{-1}). There was no significant trend in Queenstown Bay or the open water site.

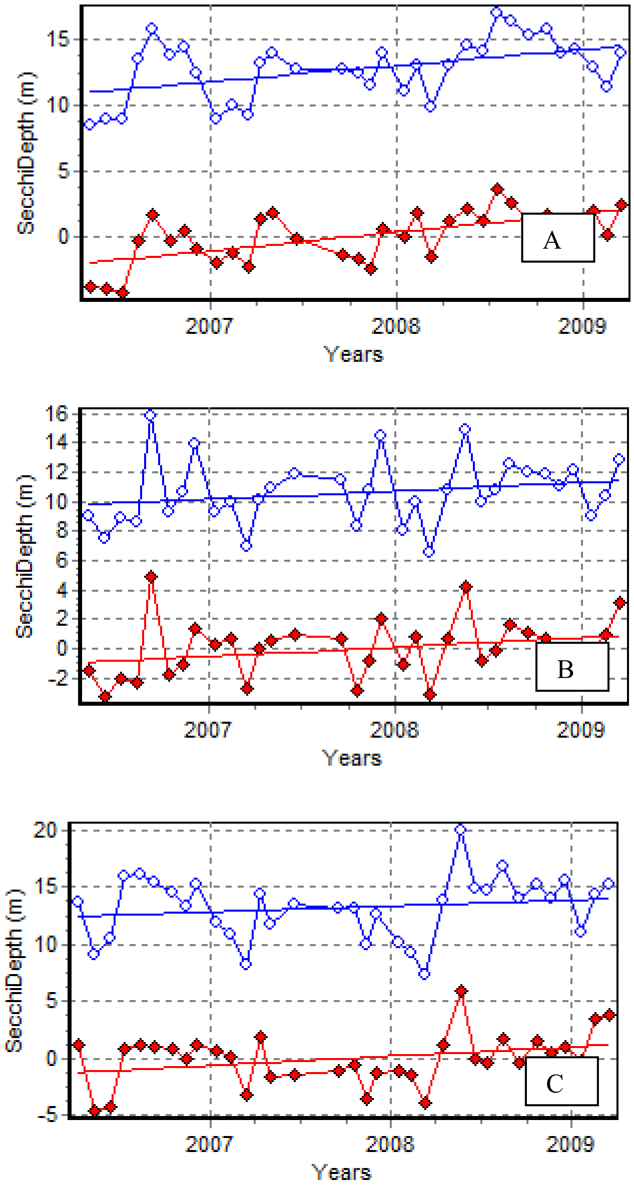

Figure 7.8 **Lake Wakatipu: Plot of observed and deseasonalised time trends for secchi depth (A=Frankton Arm, B=Queenstown Bay, C=open water)**

7.9 Nutrients (total phosphorus and total nitrogen) time trend

The deseasonalised TP data shows no significant trend for any site (Figure 7.9).

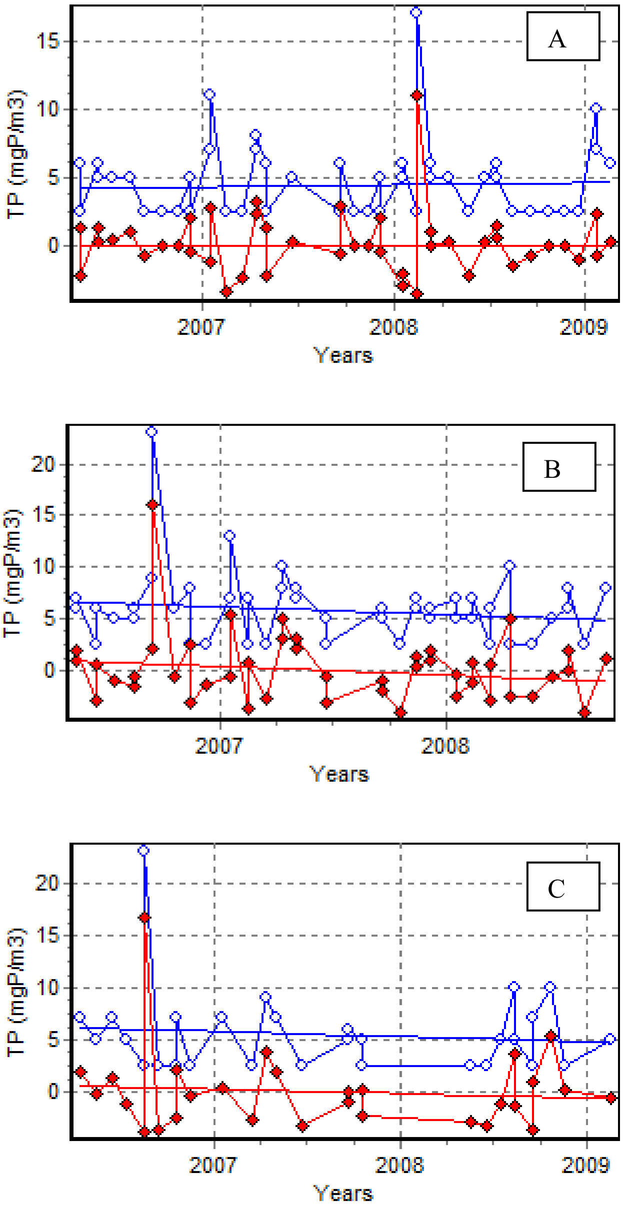

Figure 7.9 Lake Wakatipu: Plot of observed and deseasonalised time trends for total phosphorus (A=Frankton Arm, B=Queenstown Bay, C=open water)

Total nitrogen in the Frankton Arm has a decreasing trend of 10.92mg m^{-3} year^{-1} (Figure 7.10), Queenstown Bay shows TN increasing by 20.62 mg m^{-3} year^{-1}, and the open water site shows TN increasing by 3.52 mg m^{-3} year^{-1}. At no site was the trend significant.

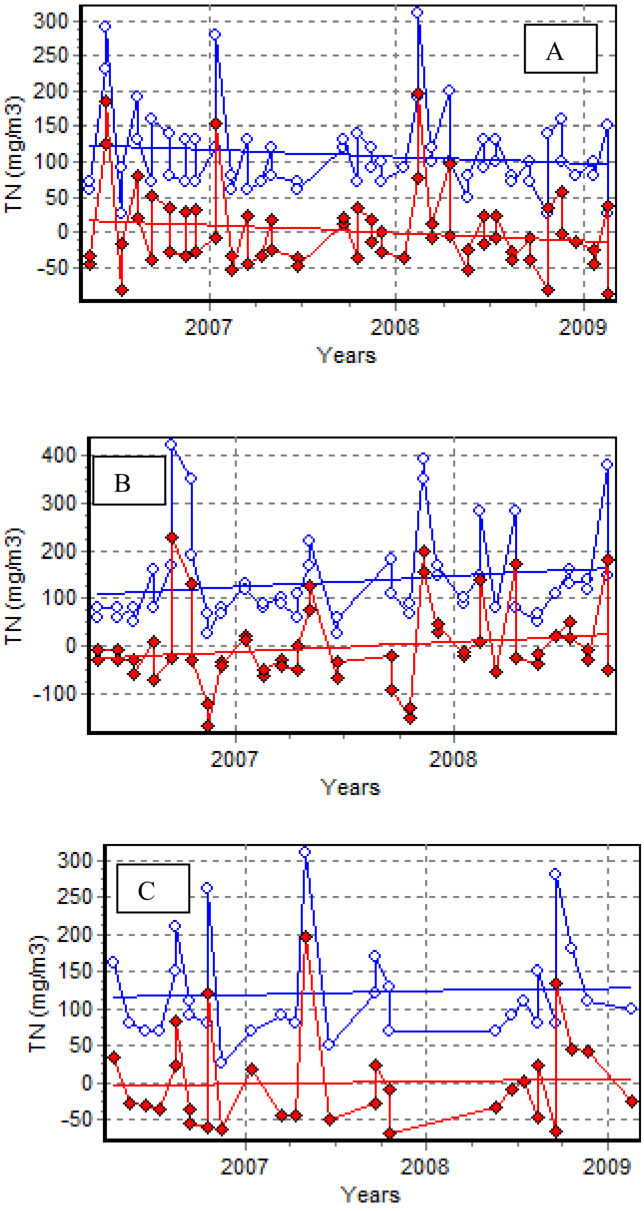

Figure 7.10 **Lake Wakatipu: Plot of observed and deseasonalised time trends for total nitrogen. (A=Frankton Arm, B=Queenstown Bay, C=open water)**

7.10 Dissolved Oxygen (DO) and Hypolimnetic Volumetric Oxygen Depletion (HVOD) rates

HVOD rates are determined by the rate of change of DO in the hypolimnion. HVOD rates are calculated for the three summers when the lake was monitored. The HVOD plots are shown in Figure 7.11 and the observed HVOD rates are given by the slopes of the equations.

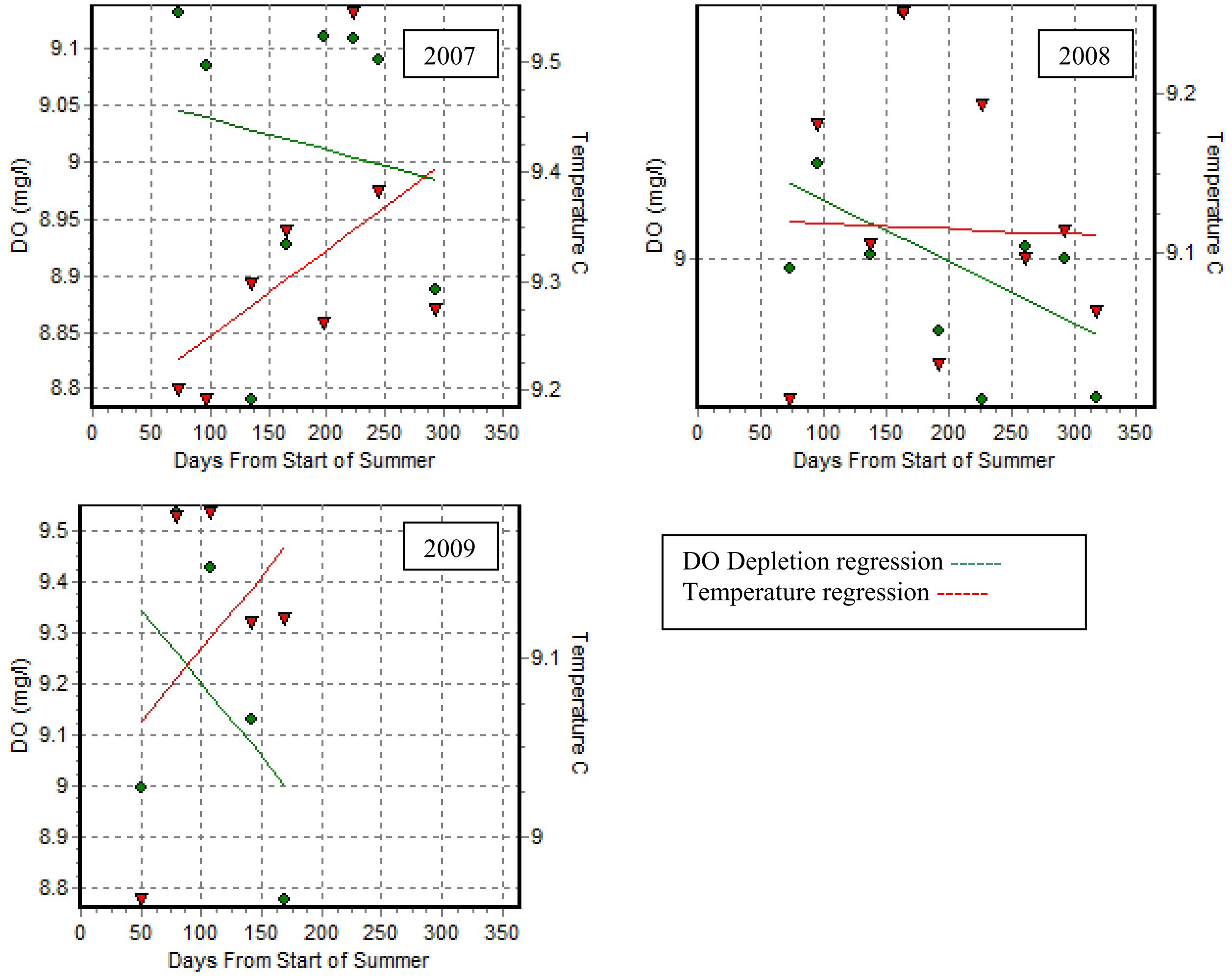

Figure 7.11 **Seasonal DO and temperature plots for the calculation of HVOD rates for Lake Wakatipu from 2007 to 2009 (summer starts on 1 September)**

These values and the average hypolimnion temperatures during the periods of HVOD rate measurement are shown in Table 7.2. Since HVOD can be changed by temperature, the rates have been adjusted to a standard temperature to make them more comparable (Burns, 1995). The standard temperature chosen for Lake Wakatipu was 9.1°C, as this results in minimum change in the rates when adjusting from observed values to temperature adjusted values. The temperature adjusted rates are also shown in Table 9.2.

Figure 7.12 shows that there was no significant trend in the HVOD rates from 2006 to 2009.

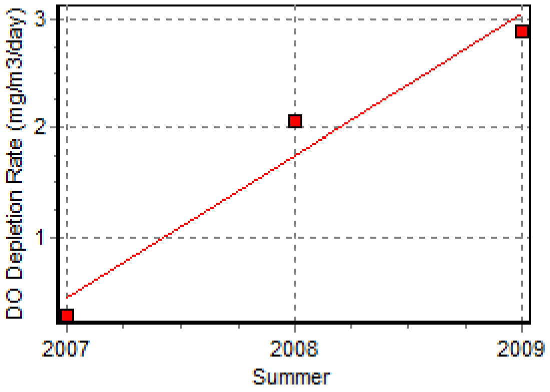

Figure 7.12 Plot of observed HVOD rate and the HVOD rate corrected to a standard hypolimnion temperature of 9.5°C for Lake Wakatipu from 2006 to 2009

Table 7.2 Observed and adjusted HVOD rates. Lake Wakatipu 2006 to 2009

Summer	Average Temp °C	Observed DO depletion rate °C (mg m^3 day-1)	Observed rate at 9.1 °C (mg m^3 day-1)
2006/2007	9.312	0.280	0.276
2007/2008	9.115	2.067	2.065
2008/2009	9.114	2.895	2.892

7.11 Percent Annual Change: Results

The PAC values are calculated using the annual change values obtained from the slopes of the four key variables (chla, secchi depth, TN and TP) that show significant change. This calculation is described in Appendix 2.

Only PAC values calculated from significant trend lines are considered indicative of change in a particular variable. Algal biomass in the Frankton Arm and Queenstown Bay and clarity in the Frankton Arm were the only variables with significant slopes; otherwise the PAC values were replaced by a value of 0.00 (Table 7.3).

Table 7.3 PAC results for Lake Wakatipu

	Chla (mg/m^3)	SD (m)	TP (mg/m^3)	TN (mg/m^3)
Frankton Arm				
Change - units per year	0.08	1.41	(-0.03)	(-10.92)
Average over period	0.39	12.78	(4.44)	(108.33)
Percent annual change (%/year)	20.51	-11.03	0.00	0.00
Queenstown Bay				
Change - units per year	0.17	(0.64)	(-0.84)	(20.62)
Average over period	0.43	(10.61)	(5.79)	(136.60)
Percent Annual Change (%/year)	39.53	0.00	0.00	0.00
Open water				
Change - units per year	(0.03)	(0.82)	(-0.41)	(3.53)
Average over period	(0.36)	(13.24)	(5.50)	(121.50)
Percent Annual Change (%/year)	0.00	0.00	0.00	0.00

The decision on whether a lake has changed over time is made by looking at the p-value of the PAC average. The PAC values for the three years of monitoring Lake Wakatipu are shown in Table 7.3. All sites had a p-value of >0.3, which means that the lake is not changing its trophic state (Table 7.4).

Table 7.4 Lake Wakatipu: PAC averages and p-value

Site	PAC and p-value
Frankton Arm	PAC = 2.37 ± 6.58 % per year p-value = 0.74
Queenstown Bay	PAC = 9.88 ± 9.88 % per year p-value = 0.39
Open Water	PAC = 0.00 ± 0.00 % per year p-value = 1.00

7.12 Trophic Level Index: Results

The TLI values are calculated next. This calculation is described Appendix 2. The annual average values are taken from the three years of data shown in Table 7.5.

Table 7.5 Lake Wakatipu: Average annual values for the four key variables

	Chla (mg/m^3)	SD (m)	TP (mg/m^3)	TN (mg/m^3)
Frankton Arm				
May 2006 - Apr 2007	0.3	11.47	4.38	116.88
May 2007 - Apr 2008	0.42	12.44	4.8	118.5
May 2008 - Apr 2009	0.47	14.5	4.13	92.83
Averages	0.40	12.80	4.44	109.40
Queenstown Bay				
May 2006 - Apr 2007	0.33	9.99	6.44	116.88
May 2007 - Apr 2008	0.42	10.31	5.38	156.25
May 2008 - Apr 2009	0.56	11.55	5.69	118.81
Averages	0.44	10.62	5.83	130.64
Open water				
Apr 2006 - Apr 2006	0.49	13.6	7	160
May 2006 - Apr 2007	0.3	12.98	6	106.54
May 2007 - Apr 2008	0.44	11.49	4.67	141.67
May 2008 - Apr 2009	0.34	15.08	5.04	124.17
Averages	0.39	13.29	5.68	133.09

The trophic level values for each of the variables and TLI values generated from these numbers are shown in Table 7.6, as are the average TLI values from the two most recent years of data.

Table 7.6 Lake Wakatipu: TLI values derived from the average annual values

	TLc	TLs	TLp	TLn	TLI average
Frankton Arm					
May 2006 - Apr 2007	0.91	2.42	2.09	2.61	2.01
May 2007 - Apr 2008	1.26	2.29	2.21	2.63	2.1
May 2008 - Apr 2009	1.39	2.03	2.02	2.31	1.94
Averages	1.19	2.25	2.10	2.52	2.01
Queenstown Bay					
May 2006 - Apr 2007	0.99	2.64	2.58	2.61	2.21
May 2007 - Apr 2008	1.27	2.59	2.35	2.99	2.3
May 2008 - Apr 2009	1.58	2.41	2.42	2.64	2.26
Averages	1.28	2.55	2.45	2.75	2.26
Open water					
Apr 2006 - Apr 2006	1.43	2.14	2.69	3.02	2.32
May 2006 - Apr 2007	0.91	2.22	2.49	2.49	2.03
May 2007 - Apr 2008	1.3	2.42	2.17	2.87	2.19
May 2008 - Apr 2009	1.04	1.96	2.27	2.69	1.99
Averages	1.17	2.19	2.40	2.77	2.13

TLI values and trends for each site are shown in Table 7.7.

Table 7.7 Lake Wakatipu: TLI value and trend for each site

Site	TLI time trend
Frankton Arm	TLI value = 2.01 ± 0.16 TLI units TLI trend = -0.04 ± 0.20 TLI units per year p-value = 0.8676
Queenstown Bay	TLI value = 2.26 ± 0.18 TLI units TLI trend = 0.03 ± 0.23 TLI units per year p-value = 0.9030
Open water	TLI value = 2.13 ± 0.16 TLI units TLI trend = -0.08 ± 0.15 TLI units per year p-value = 0.5807

The average values for the clarity and nutrients fall into the same trophic category (oligotrophic) at each site; however, the average value for algal biomass falls into a lower trophic category (microtrophic).

The TLI trend is in different units to the PAC value but is in qualitative agreement with it. The combined PAC and TLI trend information yields the conclusion that at each site Lake Wakatipu is oligotrophic and not changing state.

7.13 Plots of other data (NNN, NH4, DRP, pH, DO, temperature, internal seiche)

Several variables other than those termed key variables were monitored as part of the programme. Figures 7.13 to 7.17 show seasonal trend plots for nitrite-nitrate nitrogen (NNN), ammoniacal nitrogen (NH4), dissolved reactive phosphorus (DRP), pH and DO. Turbidity was not plotted as values were always low.

Figures 7.18 to 7.19 show plots of temperature and DO that demonstrate that the lake did not stratify during the monitoring period.

NNN is shown in Figure 7.13. All sites show minimum concentrations in late summer, peaking between September and November. No site shows a trend of change with time.

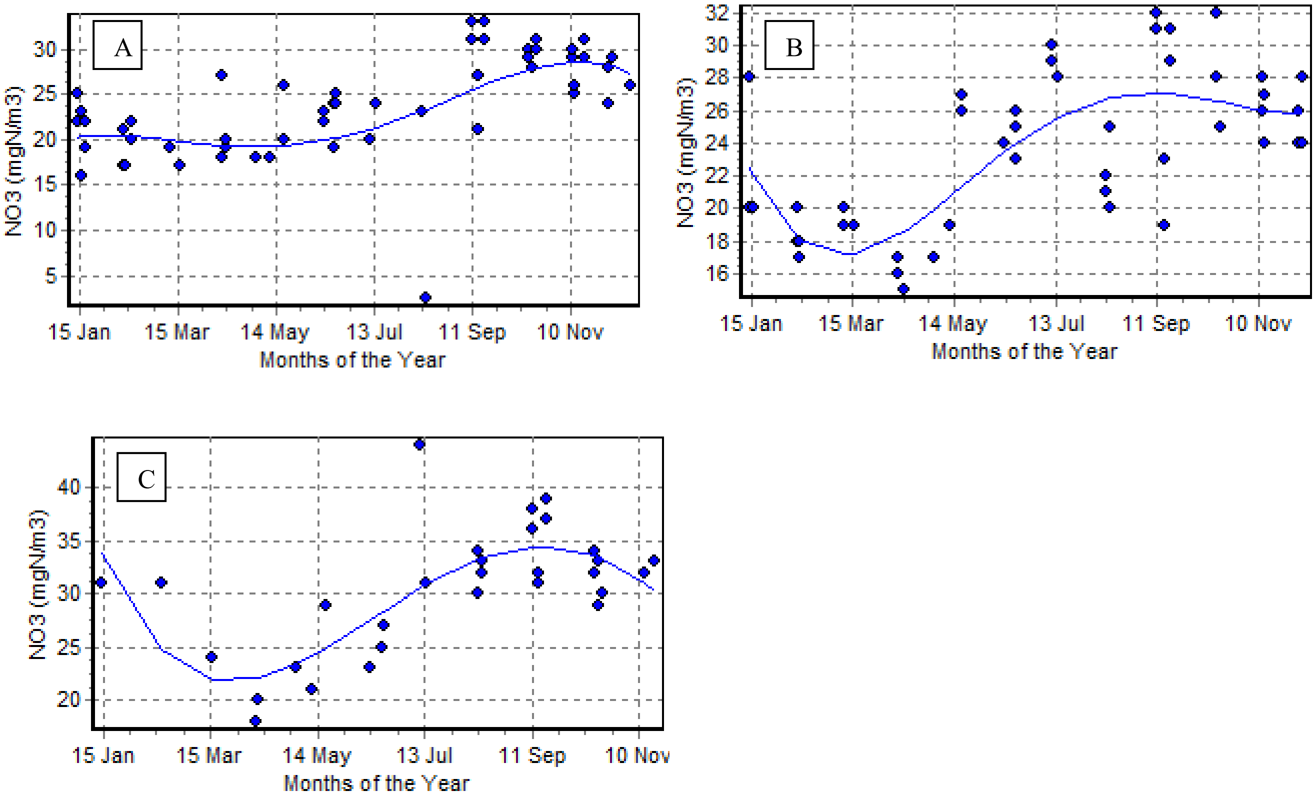

Figure 7.13 Lake Wakatipu: Epilimnetic nitrite-nitrate nitrogen plotted against month of year. (A=Frankton Arm, B=Queenstown Bay, C=open water)

Figure 7.14 shows that concentrations of ammoniacal nitrogen are low at every site (generally either 0.005 mg/l or 0.01 mg/l, hence the stepped appearance of the results). No seasonal trends are apparent and no time trends are apparent.

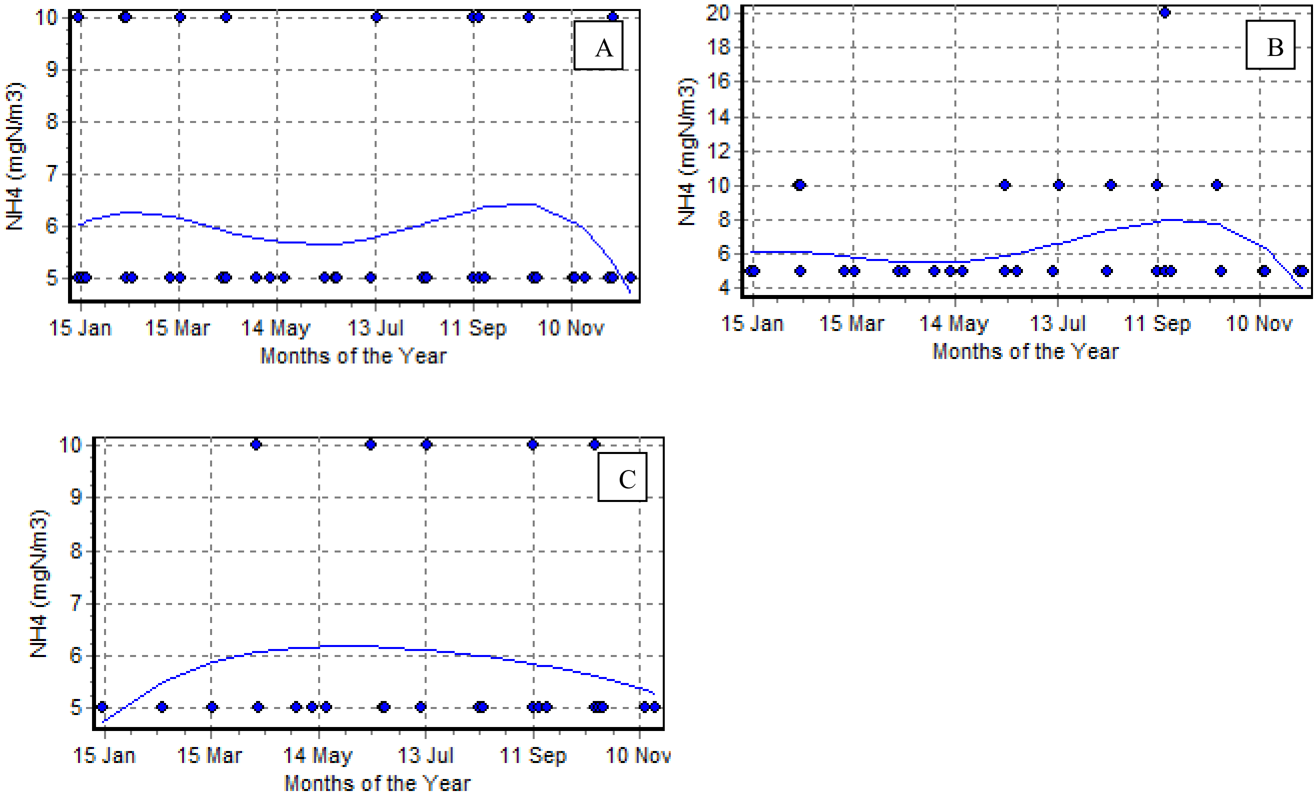

Figure 7.14 **Lake Wakatipu: Epilimnetic ammoniacal nitrogen plotted against month of year (A=Frankton Arm, B=Queenstown Bay, C=open water)**

Figure 7.15 shows the annualised data for DRP. It shows that the DRP content of the surface waters increases from March to peak around September/October. It then decreases as summer progresses. This is likely to be due to its removal by algae. The concentrations are very low. There is no significant trend.

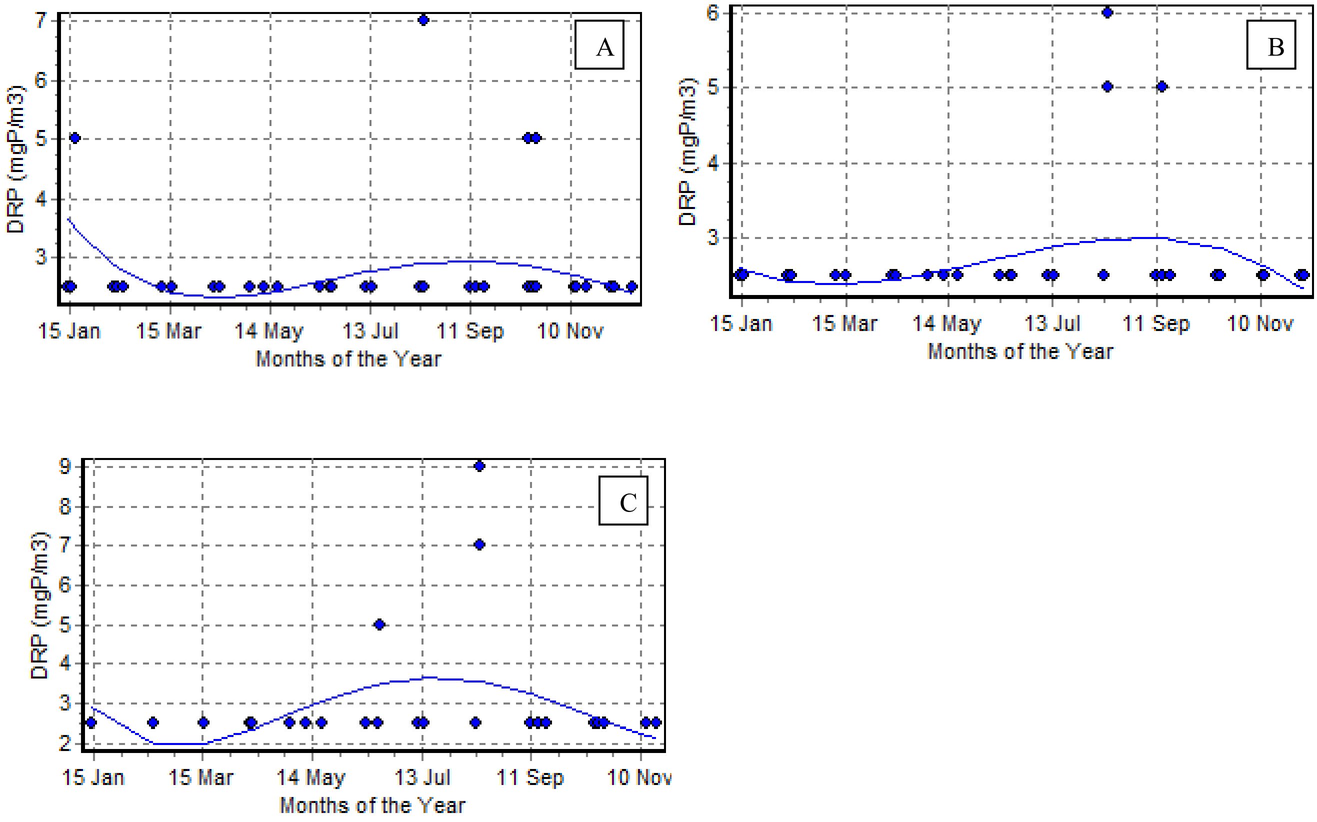

Figure 7.15 Lake Wakatipu: Epilimnetic dissolved reactive phosphorus plotted against month of year. (A=Frankton Arm, B=Queenstown Bay, C=open water)

Figure 7.16 shows the pH conditions. There is a seasonal trend, with the epilimnetic pH increasing in the summer months, probably as a result of some algal growth.

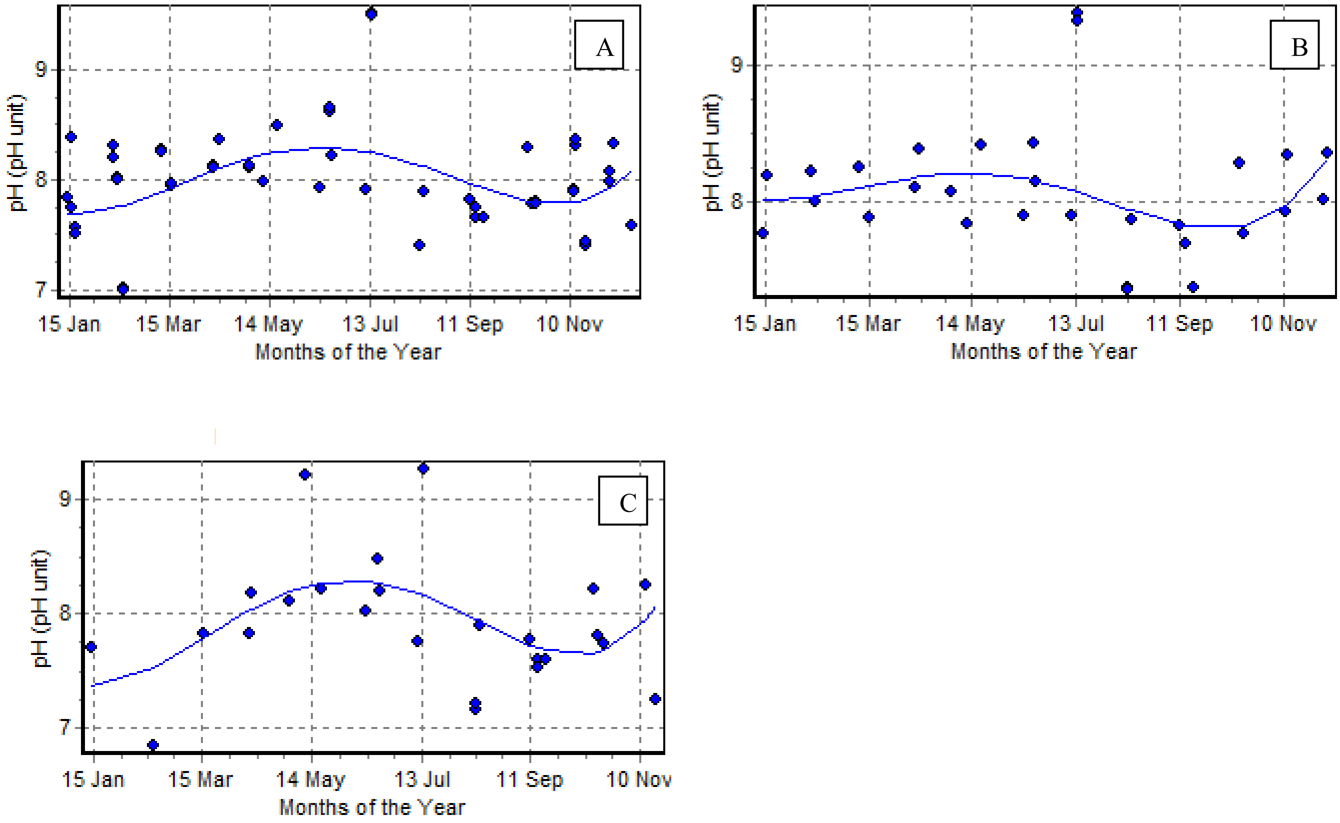

Figure 7.16 Lake Wakatipu: Epilimnetic pH plotted against month of year (A=Frankton Arm, B=Queenstown Bay, C=open water)

Figure 7.17 shows that dissolved oxygen concentrations are at their highest in autumn and winter. The low concentration of algae found in the lake means that there is no summer peak associated with algal blooms.

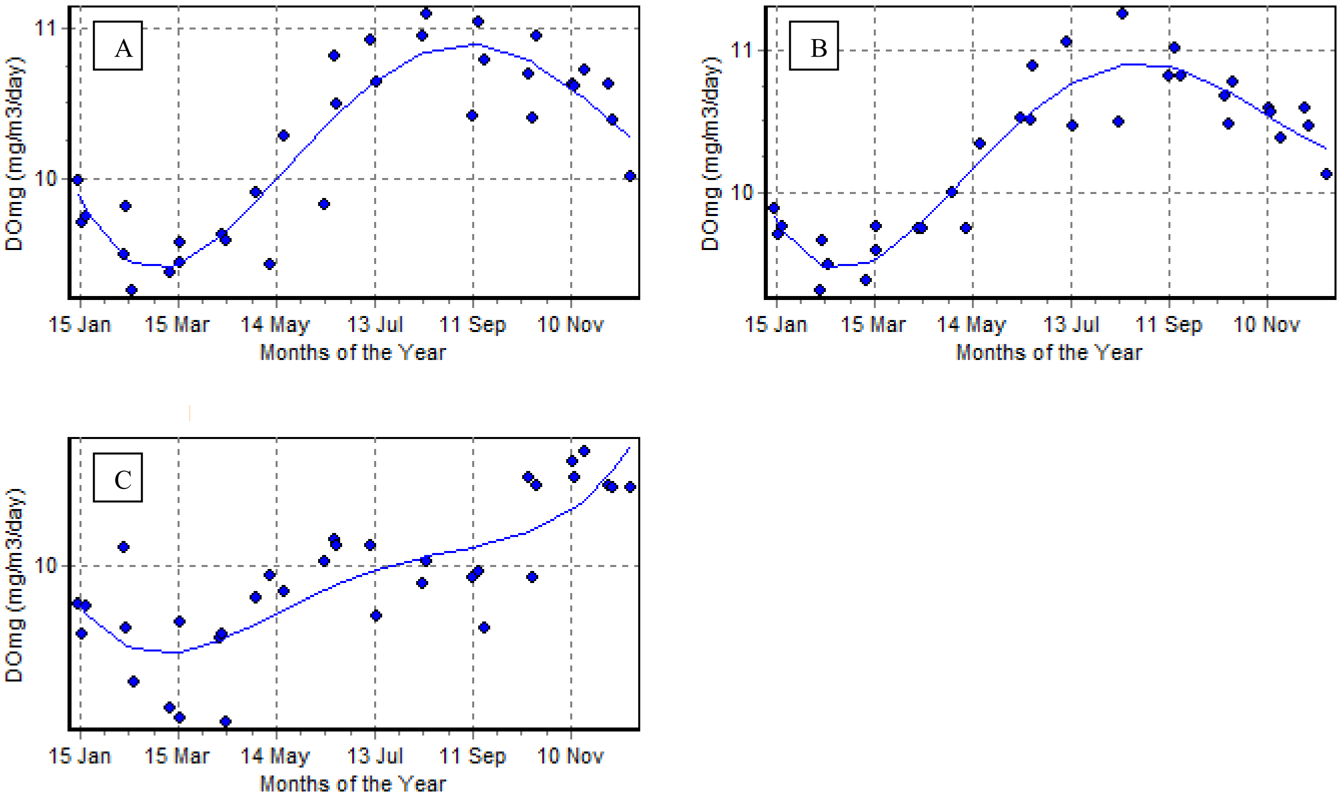

Figure 7.17 Lake Wakatipu: Epilimnetic dissolved oxygen plotted against month of year. (A=Frankton Arm, B=Queenstown Bay, C=open water)

Depth profiles of dissolved oxygen (DO) and temperature were measured at the open water site at about monthly intervals throughout the year. The data shown in Figures 7.18 and 7.19 indicate that the lake did not mix and that, at 130m, temperatures were approximately 10°C lower than surface temperatures. Figure 7.19 shows dissolved oxygen to be about 1mg/l less at 130m than at 20m.

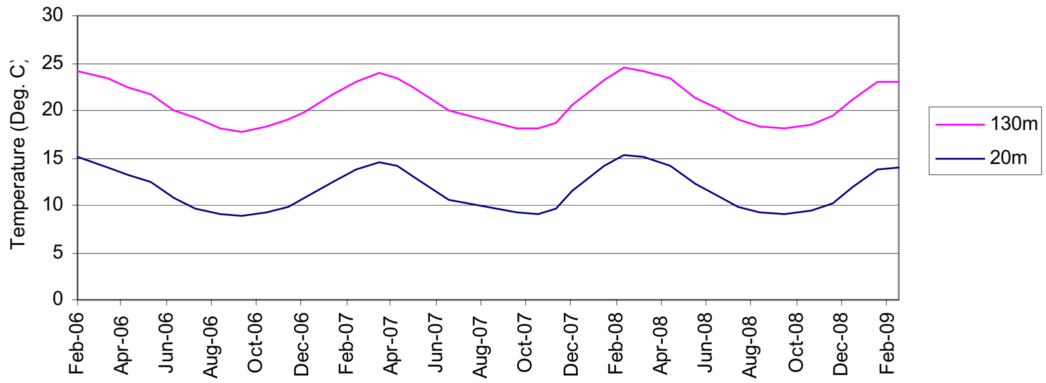

Figure 7.18 **Time series temperature at 20m (pink) and 130m (blue) depths. The two lines do not meet indicating that there was no mixing during the monitoring period**

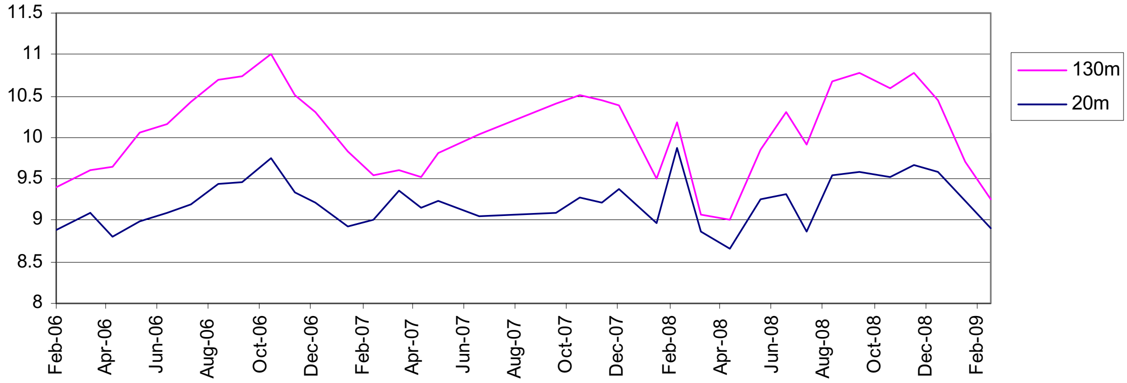

Figure 7.19 **Time series dissolved oxygen (mg/l) at 20m (pink) and 130m (blue) depths. As the two lines do not meet, the data show no mixing occurred during the monitoring period**

7.14 Discussion

Lake Wakatipu was monitored at three sites: Queenstown Bay, Frankton Arm and an open water site. The size of Lake Wakatipu relative to the percentage of modified catchment means that eutrophication of the open water is unlikely. However, the major resort town of Queenstown lies on the shores of Queenstown Bay, which is an enclosed arm with the potential for nutrient enhancement.

All the sites on Lake Wakatipu were sampled on the same days; therefore, pairwise t-test comparisons for each site with all other sites were undertaken to determine differences in water quality indices between the sites. Of the twelve paired sites analysed, four were significantly different. These are shown in Table 7.8.

Table 7.8 Pairwise t-tests to test for differences in water quality between sites

		Chlorophyll a	Secchi depth	Total nitrogen	Total phosphorus
Frankton Arm/ Open water	P-value	0.361	0.451	0.569	0.0162
	Reject null hypothesis?	No	No	No	Yes
Frankton Arm/ Queenstown Bay	P-value	0.209	2.4310^{-5}	0.850	2.6910^{-3}
	Reject null hypothesis?	No	Yes	No	Yes
Open water/ Queenstown Bay	P-value	0.974	5.810^{-6}	0.335	0.618
	Reject null hypothesis?	No	Yes	No	No

Clarity (secchi depth) was significantly different between the Frankton Arm/Queenstown Bay and open water/Queenstown Bay sites, and TP was significantly different between the Frankton Arm/open water and Frankton Arm/ Queenstown Bay sites. Figure 7.20 shows these differences.

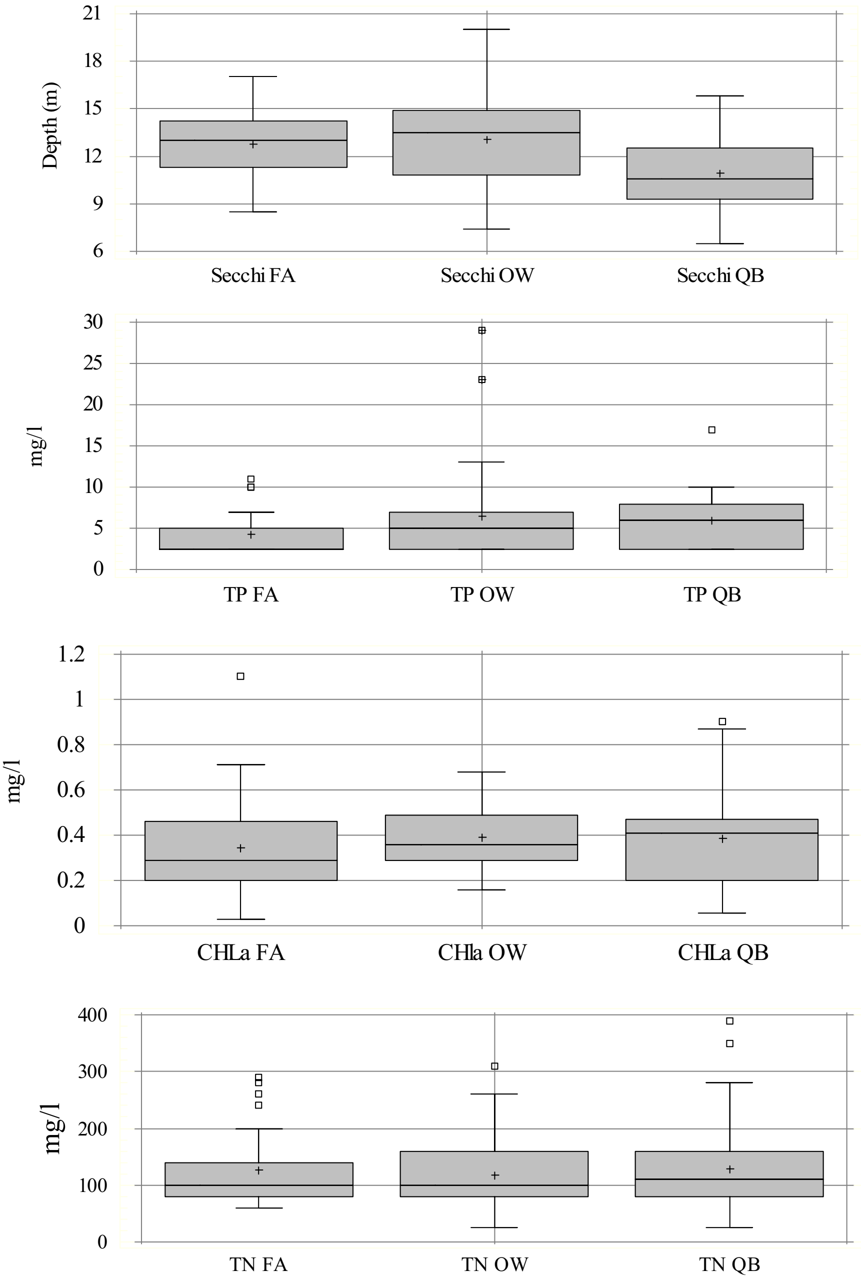

Figure 7.20 **Box and whisker plots of secchi depth, total phosphorus, chla and total nitrogen at the three monitoring sites in Lake Wakatipu (FA = Frankton Arm, OW = open water and QB = Queenstown Bay)**

Data from all three sites were available from both 1997/1998 (Schallenberg et al. 1999) and this survey. To compare the two data sets, only the months of data available from the 1997/1998 survey were taken from the 2006/2009 survey. An analysis of variance of the four key variables was then undertaken. The results are presented in Table 7.9. Only the Frankton Arm showed significant differences; chla and total phosphorus showed a significant decrease, but total nitrogen showed a significant increase. Schallenberg and Burns (1999) had also noted a significant difference in total nitrogen concentrations between 1997 and 1998 (Graham, 1989) and 1992 and 1995 (Burns and Rutherford, 1999), but were unclear if this was an artefact due to the small data set or seasonality of sampling.

Table 7.9 Analysis of variance to test for differences in water quality between sites from the 1997 to 1998 period and the 2006 to 2009 period

1997 - 1998	2006 - 2009		Chlorophyll a	Secchi disc	Total nitrogen	Total phosphorus
Frankton Arm	Frankton Arm	P-value	0.0206	0.4349	0.0172	0.0732
		Significant difference?	Yes	No	Yes	Yes
Queenstown Bay	Queenstown Bay	P-value	0.8010	0.5197	0.1365	0.2102
		Significant difference?	No	No	No	No
Open water	Open water	P-value	0.2192	0.3360	0.0529	0.6386
		Significant difference?	No	No	No	No

Clarity data were available in the Frankton Arm for five periods; 1952 to 1953 (three samples, Jolly, 1968), 1988 to 1990 (six samples, Graham, 1989, Burns, unpublished), 1992 to 1995, (33 samples, Burns, 1999), 1997 to 1998 (six samples, Schallenberg et al. 1999) and 2006 to 2009 (35 samples, ORC).

A multiple comparison procedure was undertaken to determine which means were significantly different from each other. Four pairs had statistically significant differences at the 95.0% confidence level, (1952/3 and 1997/8, 1988/90 and 1992/95, 1992/95 and 1997/98, 1992/95 and 2006/09). Figure 7.22 shows the differences between the years.

Schallenberg and Burns (1999) have reported that clarity was unusually low in 1994, explaining the significant improvement from this period to the 2006 to 2009 period. Figure 7.21 shows box whisker plots of secchi depth for five time periods, clearly showing this study recorded greater depths than recorded in 1952-53 and 1992-95.

The Frankton Arm has the majority of historical water quality data. Between 1997/1998 and 2006/2009, TN showed a statistically significant increase. However, this study did not show a continuation of this increasing trend over the monitoring period. Frankton Arm also showed a significant increase in both algal biomass and clarity.

A trend of increasing secchi depth in the Frankton Arm of 0.6m year^{-1}indicates an increase in water clarity. However, with increasing water clarity, the corresponding trend we would expect to see is one of decreasing algal biomass. This was not observed and the Frankton Arm shows a significant increase in chla of 0.08 mg m^{-3} year^{-1}. In this case, occasional extreme events in water clarity, rather than a general increase, may be the main driving force behind the observed trend. This would most likely depend on how calm the lake was, as a mirror calm lake will increase clarity.

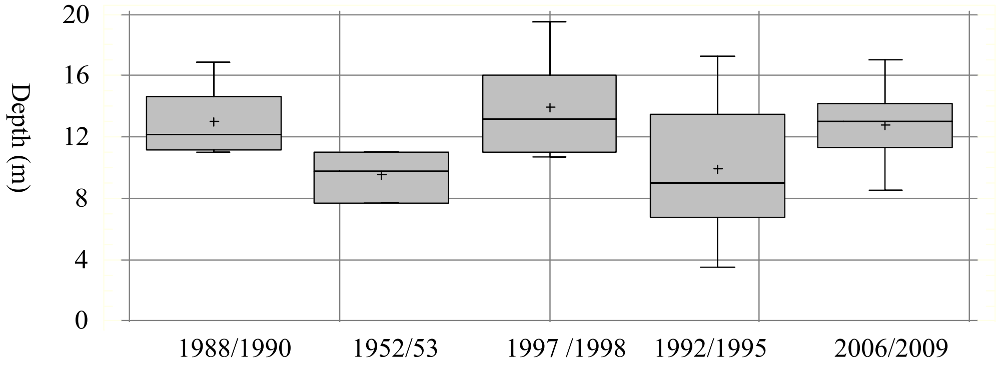

Figure 7.21 Box whisker plot of secchi depth for five time periods in the Frankton Arm of Lake Wakatipu

The Queenstown Bay site had significantly lower clarity than the other two sites (Figure 7.4), but there was no trend of it continuing to decrease. It also had higher TP concentrations than Frankton Arm (Figure 7.20). It showed a statistically significant increase in chla of 0.104 mg m^{-3} $year^{-1}$. Again this trend does not correspond to a decrease in clarity.

The open water site showed no decline in water quality over the monitoring period.

Low levels of total nitrogen, total phosphorus, algal biomass and high water clarity are all suggestive of a system with little catchment modification. Average levels of total phosphorus, total nitrogen and secchi depth are consistently indicative of an oligotrophic state, whereas levels of chla are more in line with a lower trophic level and fall into the microtrophic category. Overall lake water quality is classified as oligotrophic.

Average PAC values indicate that there has been no change in the overall lake water quality since 2006.

7.15 Conclusion

The monitoring between 2006 and 2009 shows that Lake Wakatipu appears to be in a stable state, with little change in water quality occurring over the last three years. It can currently be classified as being in an oligotrophic state, although chla falls into the microtrophic category.

Analysis of key variables showed a trend of increasing algal biomass in Frankton Arm and Queenstown Bay. None of the sites showed a trend in nutrient concentrations; however, Frankton Arm had a trend of increasing clarity. Rates of change are, however, extremely slow and it is unlikely to have any biological significance.

A water body's trophic state is largely determined by nutrient inputs from the surrounding catchment (Barnes, 2002). The major inputs into Lake Wakatipu are the Dart and Rees Rivers, both of which have glacial origins and high water quality. The immediate catchment is likely to contribute some nutrient input into the lake, especially around the township of Queenstown. Horne Creek is likely to contribute contaminants to Queenstown Bay from its agricultural, urban and industrial catchment.

In summary, TLI values have been established for Lake Wakatipu. It is classified as oligotrophic at all three sites and PAC values conclude that the TLI status is stable.

8. Lake Wanaka

8.1 General description

Lake Wanaka is 45.5km long and covers an area of 180km^2, which makes it the fourth largest New Zealand lake. Only Lakes Taupo, Te Anau and Wakatipu have greater surface areas (Irwin 1975).

Lake characteristics

	Wanaka
Lake type	Glacial
Lake area (km^2)	180
Inlet	Makarora River Matukituki River
Outlet	Clutha River
Max depth (m)	311
Catchment area (km^2)	2590

Lake Wanaka is 277m above sea level, is up to 311m deep and has a catchment area of 2590km^2 (Figure 8.1). Main inflows to the lake are the Makarora River at the north end and the Matukituki River on the south-west side. The colder, denser inflowing water sinks abruptly and flows beneath the lake water, often in well-defined sublacustrine channels (Irwin, 1980). The outflow is to the south-east by way of the Clutha River. Many small lateral streams enter the lake.

The lake has six islands: Harwich and Rabbit (or Crescent) Islands in the main body of the lake, Stevenson's Island and a smaller island in Stevenson's Arm, Ruby Island at the south end, and Bull Island near the outlet. The large central basin, Minaret Basin, is about 14.5km long and 2.0km wide.

Figure 8.1 Characteristics and location of Lake Wanaka

(Source: www.nzfishing.com)

Lake Wanaka has a number of natural values, including significant presence of trout and salmon. It is an outstanding natural feature for many reasons (listed in the Water Plan). Cultural values associated with food gathering and processing (mahika kai), the protection of nursery and breeding areas for native fish and birds (kohanga) and the recognition of the lake as a treasured resource (waahi taoka) have been identified as important in Lake Wakatipu. These and other cultural values are listed in the Water Plan. Water quality has a major impact on these values. There are no large consented discharges into Lake Wanaka, but residential and commercial development is changing the nature of the catchment, particularly around Roy's Bay, which may have an impact on future water quality.

8.2 Location and land use

The lake lies 32km east of the main divide at Mount Aspiring and 32km south west of Haast Pass. The township of Wanaka at its southern end is 56km north from Cromwell.

Lake Wanaka is of typical glacial origin, steep-sided with two large, flat-floored basins. A large delta occupies the head of the lake where the Makarora River enters.

Lake Wanaka is bordered on all sides by glaciated mountains, the northern catchment has ranges up to 1.8km high, but the southern catchment spreads out into more subdued country, where the shoreline is deeply indented by bays, the most prominent being Glendhu Bay on the west and Stevenson's Arm on the east. A number of large sheep stations lie around the lake shores, including Glendhu Bay, West Wanaka, Minarets, Mount Albert and Makarora Stations. The only parts of the lake shores that can be reached easily from public roads are at the south end of the lake and on the north-east end from the neck to the head of the lake.

Table 8.1 gives land use type in the catchment. The catchment is dominated by tall tussock grassland, indigenous forest and alpine gravel and rock.

Table 8.1 Lake Wanaka catchment land use

Land use % of total			
Alpine grass/herbfield	3.46	Indigenous forest	13.62
Alpine gravel and rock	10.21	Lake and pond	9.58
Broadleaved indig. hardwoods	0.69	Low producing grassland	6.74
Built-up area	0.21	Manuka and kanuka	1.36
Fernland	3.27	Matagouri	0.32
Gorse and broom	0.36	Orchard/other perennial crops	0.35
Deciduous hardwoods	0.24	Permanent snow and ice	2.36
Depleted tussock grassland	0.26	River	0.32
Grey scrub	0.73	River/lakeshore gravel/rocks	1.09
High producing exotic grass	3.14	Sub alpine shrubland	3.68
Tall tussock grassland	37.34	Other	0.67

8.3 Lake Wanaka: Results

Lake Wanaka had three monitoring stations located at Roy's Bay, Dublin Bay and an open water site (Figure 8.2) The three stations enabled any spatial variation in water quality to be determined.

Figure 8.2 Water quality monitoring sites on Lake Wanaka

As discussed in section 3, the key variables used to determine the trophic level of a lake are algal biomass, clarity and nutrient concentrations. Between 2006 and 2009, ORC monitored these parameters at the three sites in Lake Wanaka.

This section details results as follows:

- Seasonal trends for algal biomass, clarity and nutrients in the epilimnion
- Deseasonalised data and trends for algal biomass, clarity and nutrients in the epilimnion

8.4 Algal biomass (chla)

At all sites algal biomass concentrations are very low. At all sites concentrations tend to be highest in late summer; algae concentrations then drop off and are at their lowest in spring (Figure 8.3).

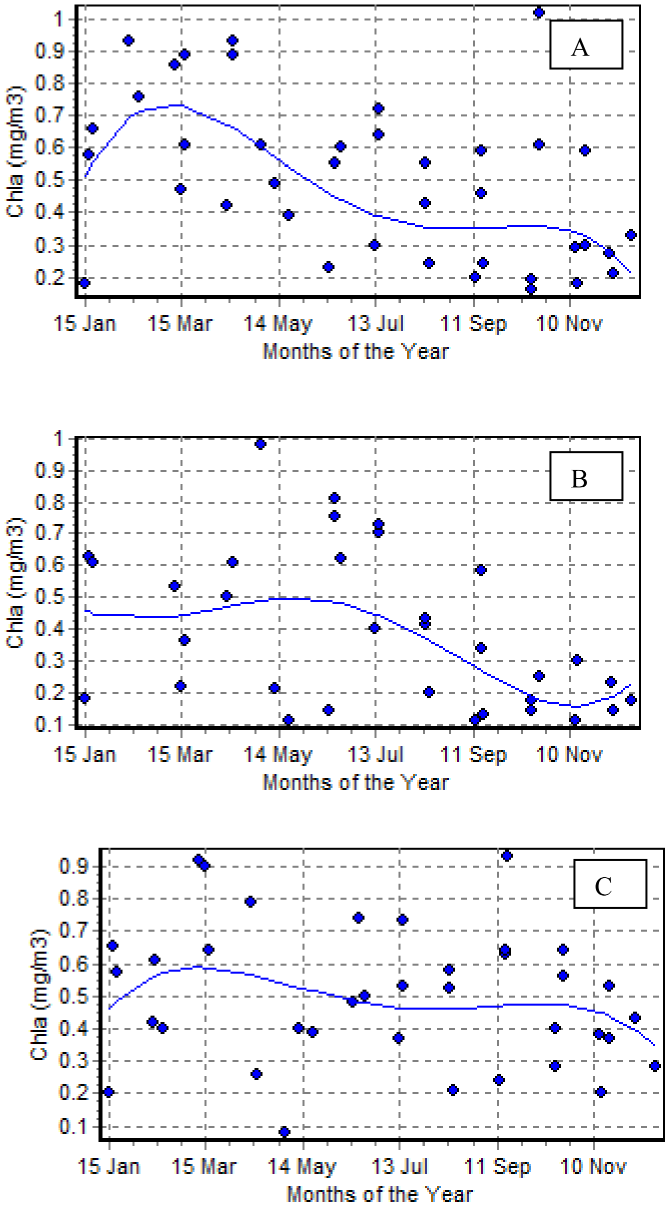

Figure 8.3 **Lake Wanaka chla plotted against month of year (A=Dublin Bay, B=Roy's Bay, C=open water)**

8.5 Clarity (secchi depth)

Figure 8.4 shows that clarity was seasonal in pattern at all sites, with a greater depth being measured in the winter months. Over the three years the depths did not vary significantly.

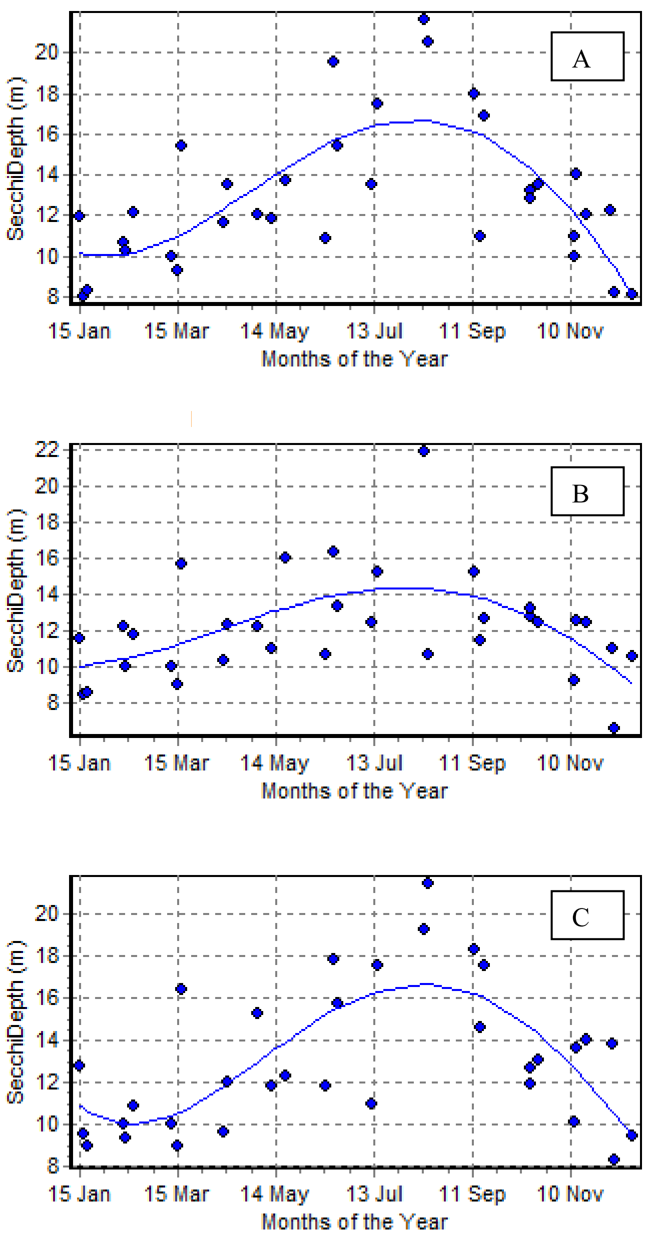

Figure 8.4 Lake Wanaka: Secchi depth plotted against month of year (A=Dublin Bay, B=Roy's Bay, C=open water)

8.6 Nutrients (total phosphorus and total nitrogen)

Epilimnetic TP concentrations remain fairly constant for most of the year, but each site shows an increase in TP concentrations during the summer months (Figure 8.5).

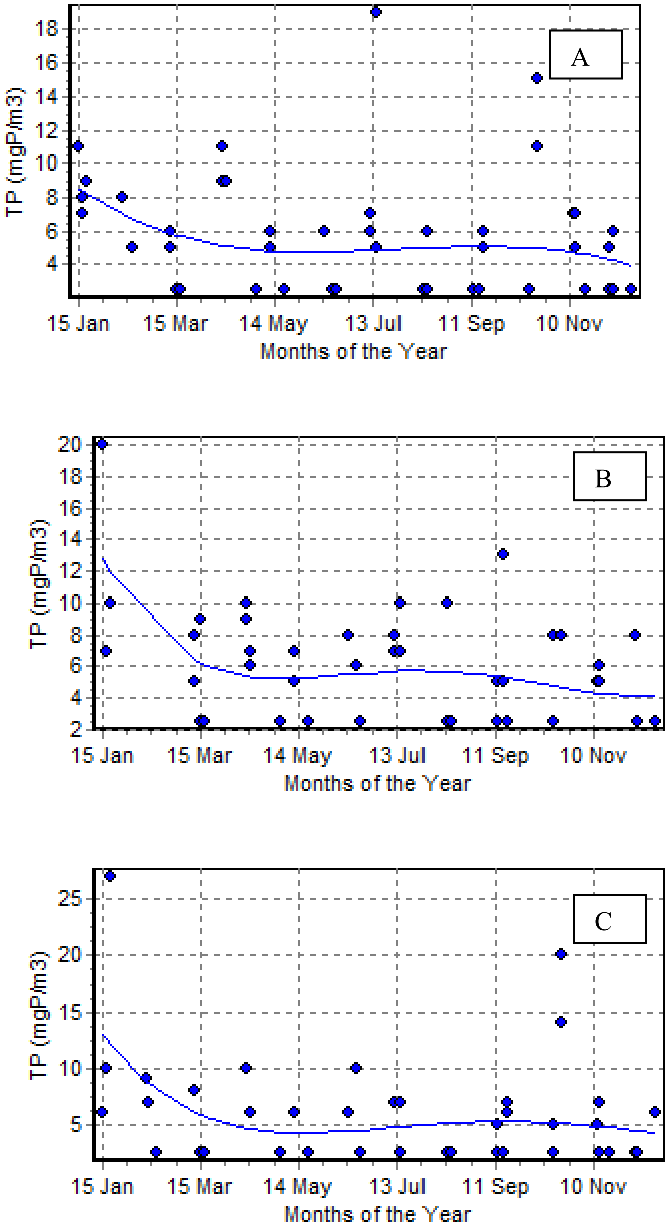

Figure 8.5 Lake Wanaka: Epilimnetic total phosphorus plotted against month of year (A=Dublin Bay, B=Roys Bay, C=open water)

Epilimnetic TN shows a lot of scatter at all sites, but, in general, TN concentrations are lower during the winter months and higher during the summer (Figure 8.6).

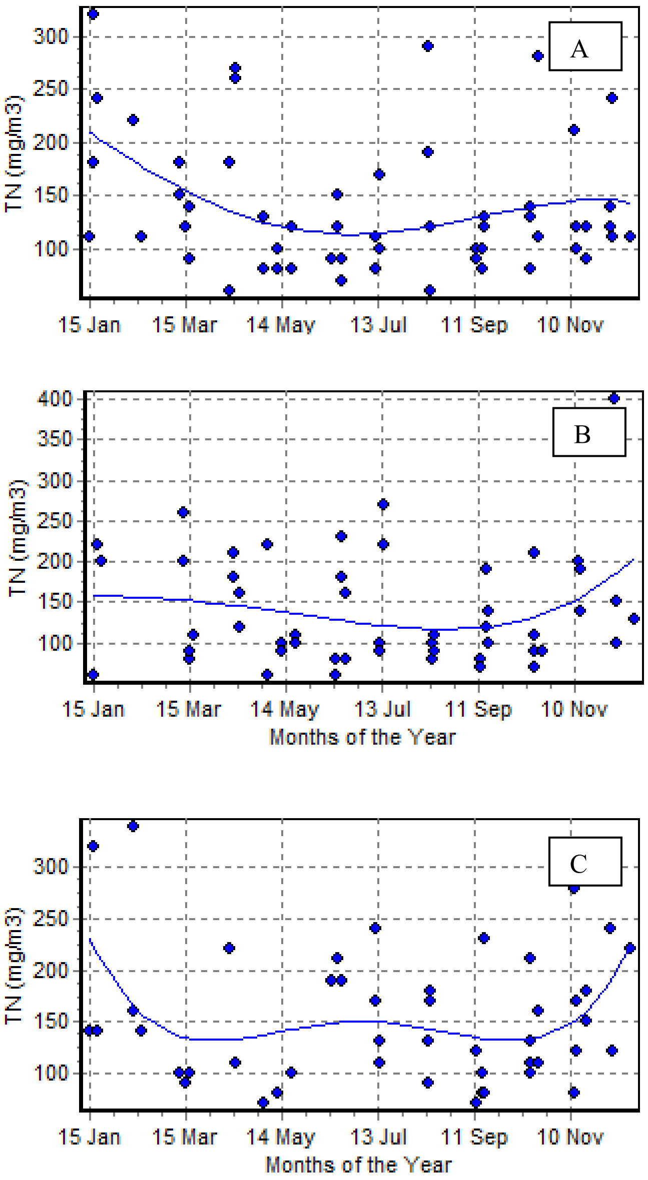

Figure 8.6 **Lake Wanaka: Epilimnetic total nitrogen plotted against month of year (A=Dublin Bay, B=Roy's Bay, C=open water)**

Figures 8.7 to 8.10 show plots of deseasonalised data over time and any trends in the three years of data.

8.7 Algal biomass (chla) time trend

All three sites show a significant ($p < 0.05$) increase in algae concentrations over the monitoring period (Figure 8.7). Dublin Bay shows an increase of 0.13 mg m^{-3} $year^{-1}$, Roy's Bay 0.1 mg m^{-3} $year^{-1}$, and the open water site shows an increase of 0.07 mg m^{-3} $year^{-1}$.

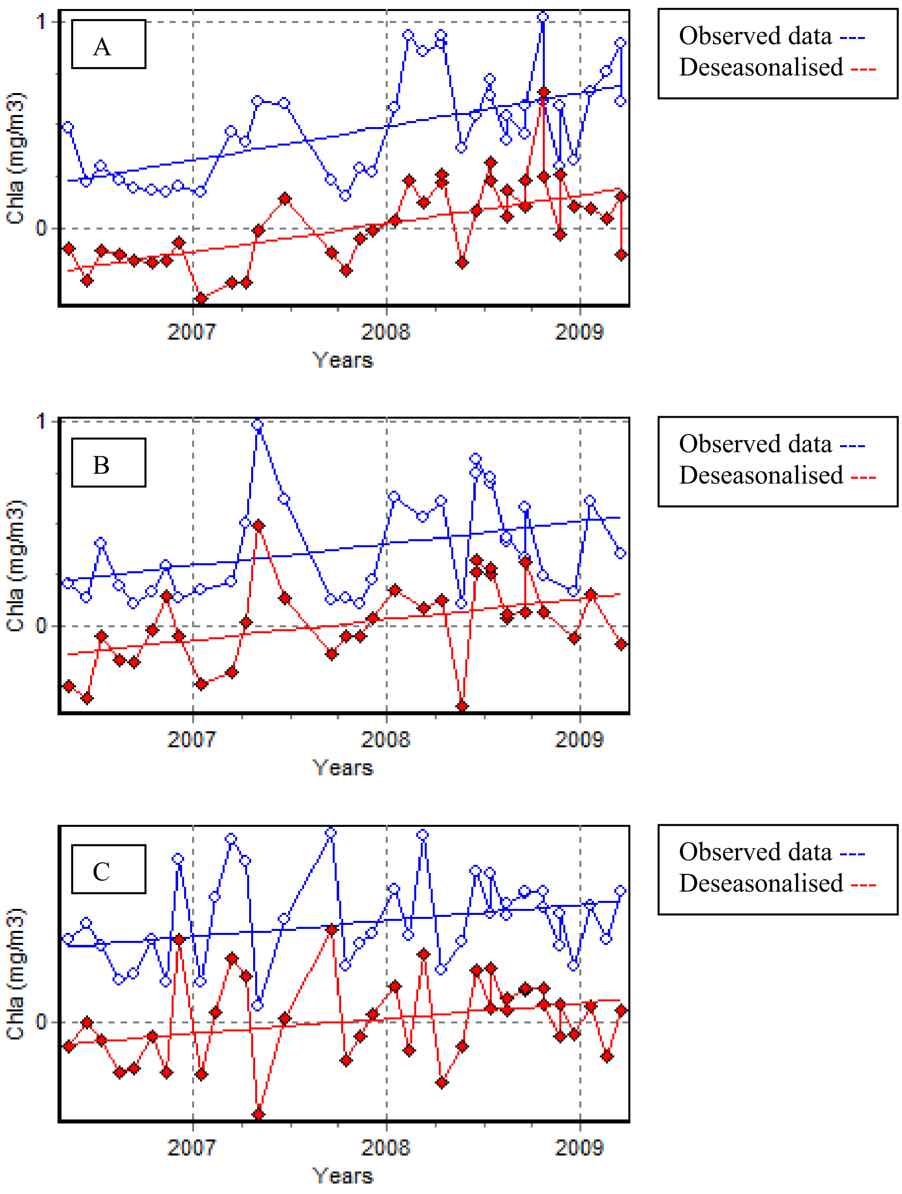

Figure 8.7 Lake Wanaka: Plot of observed and deseasonalised time trends for chla (A=Dublin Bay, B=Roy's Bay, C=open water)

8.8 Clarity (secchi depth)

In Roy's Bay there was a significant trend of SD increasing by 1.31m year^{-1}. There was no significant trend in Dublin Bay or the open water site (Figure 8.8).

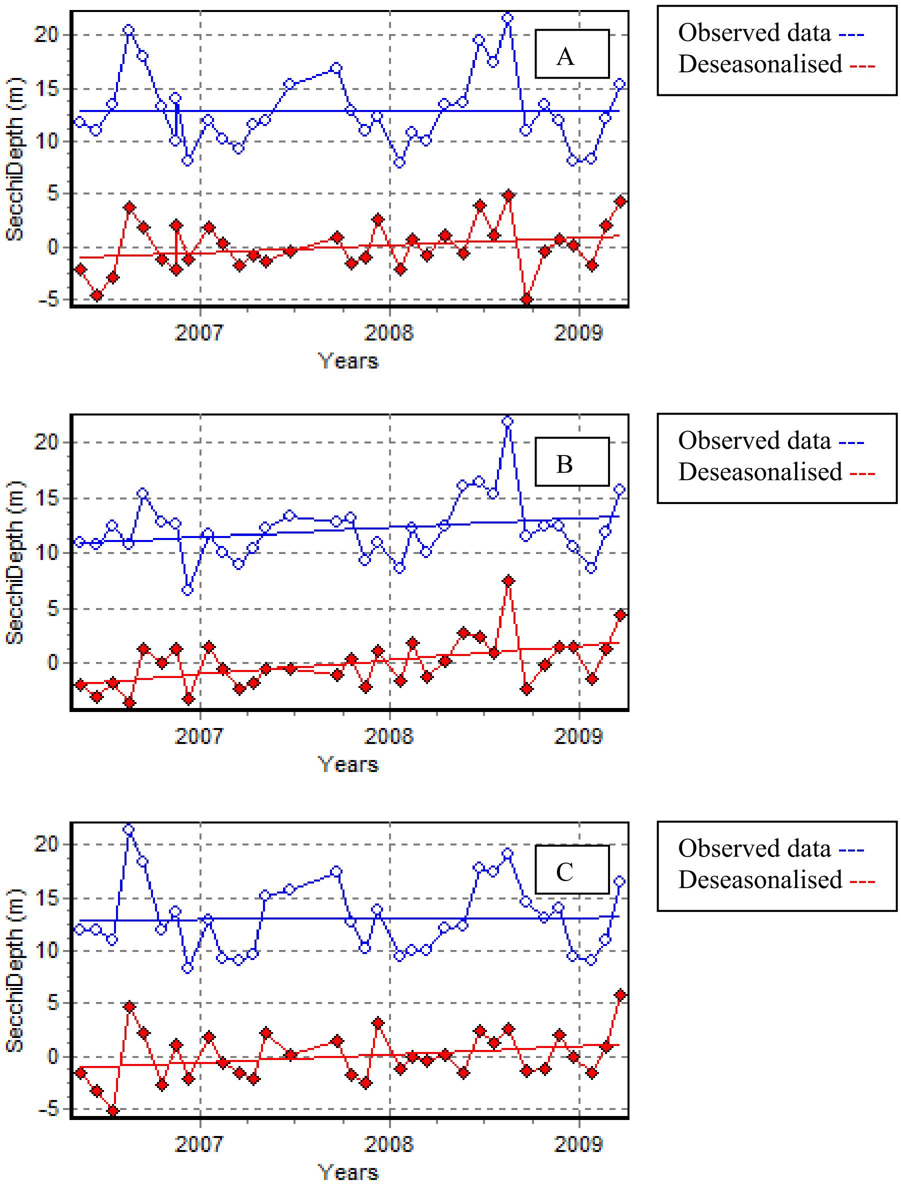

Figure 8.8 Lake Wanaka: Plot of observed and deseasonalised time trends for secchi depth (A=Dublin Bay, B=Roy's Bay, C=open water)

8.9 Nutrients (total phosphorus and total nitrogen)

The deseasonalised TP data shows no significant trend for any site (Figure 8.9).

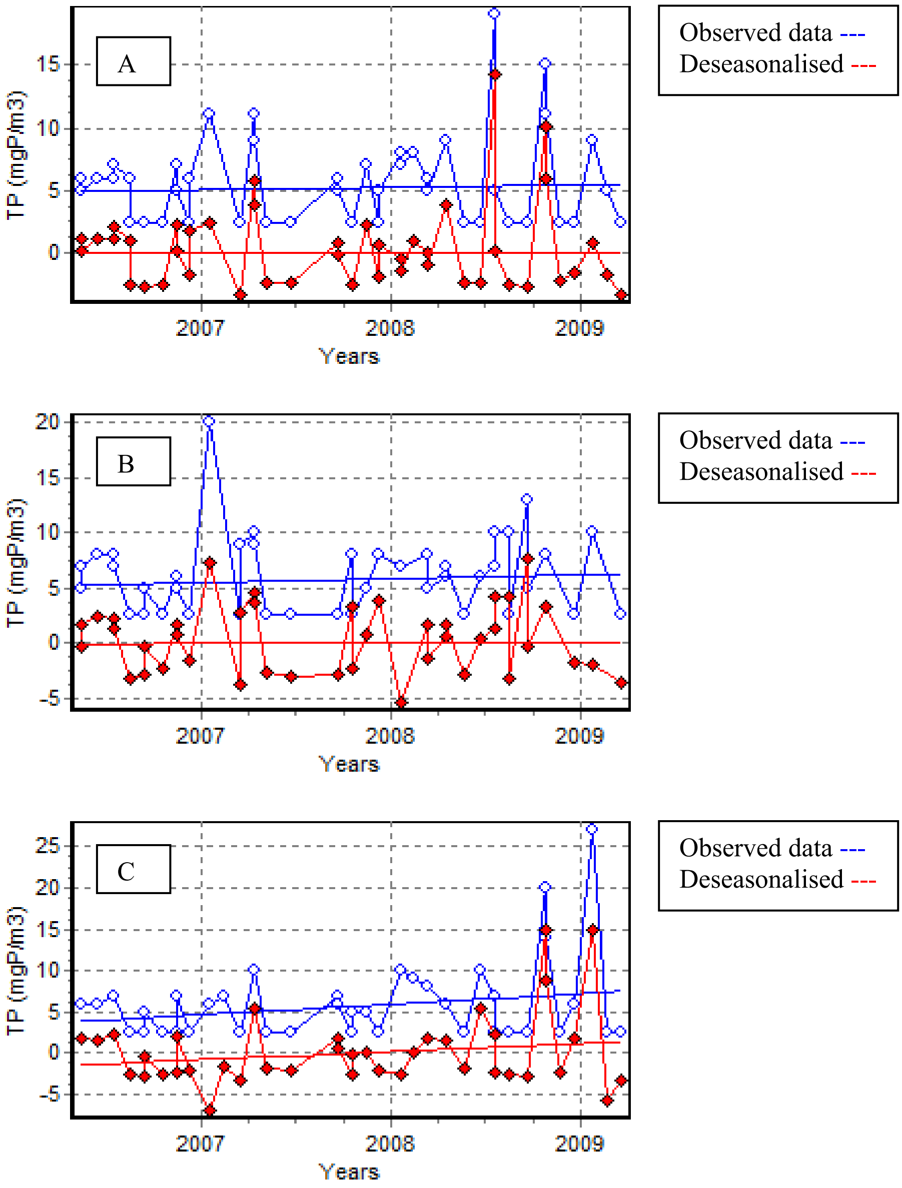

Figure 8.9 **Lake Wanaka: Plot of observed and deseasonalised time trends for total phosphorus (A=Dublin Bay, B=Roy's Bay, C=open water)**

Roy's Bay shows that TN is increasing by 28.2 mg m^{-3} year^{-1} ($p = 0.009$). Dublin Bay and the open water site do not show a significant trend (Figure 8.10).

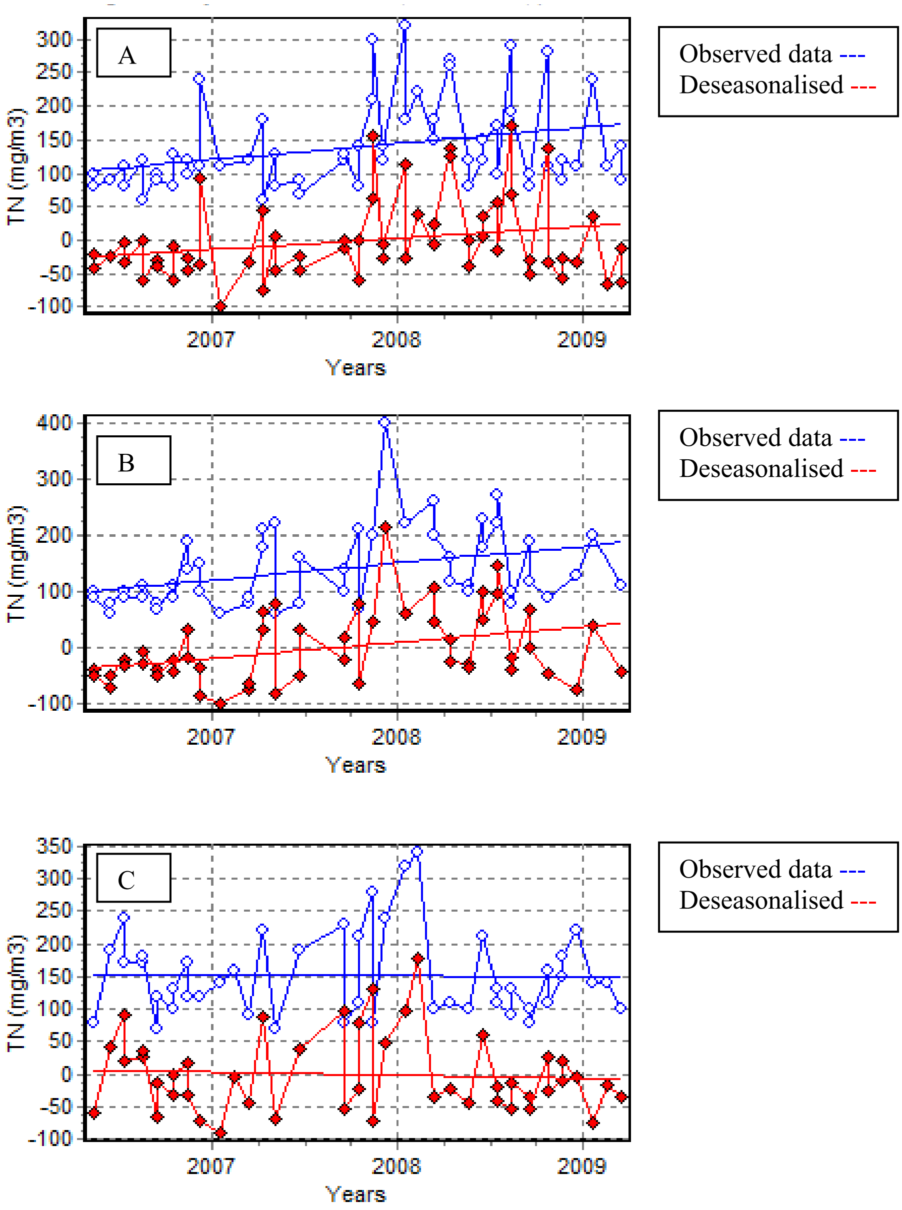

Figure 8.10 **Lake Wanaka: Plot of observed and deseasonalised time trends for total nitrogen (A=Dublin Bay, B=Roy's Bay, C=open water)**

Dissolved Oxygen (DO) and Hypolimnetic Volumetric Oxygen Depletion (HVOD) rate

HVOD rates are determined by the rate of change of DO in the hypolimnion. HVOD rates are calculated for the three summers when the lake was monitored. The HVOD plots are shown in Figure 8.11 and the observed HVOD rates are given by the slopes of the equations to the DO depletion rate trend lines.

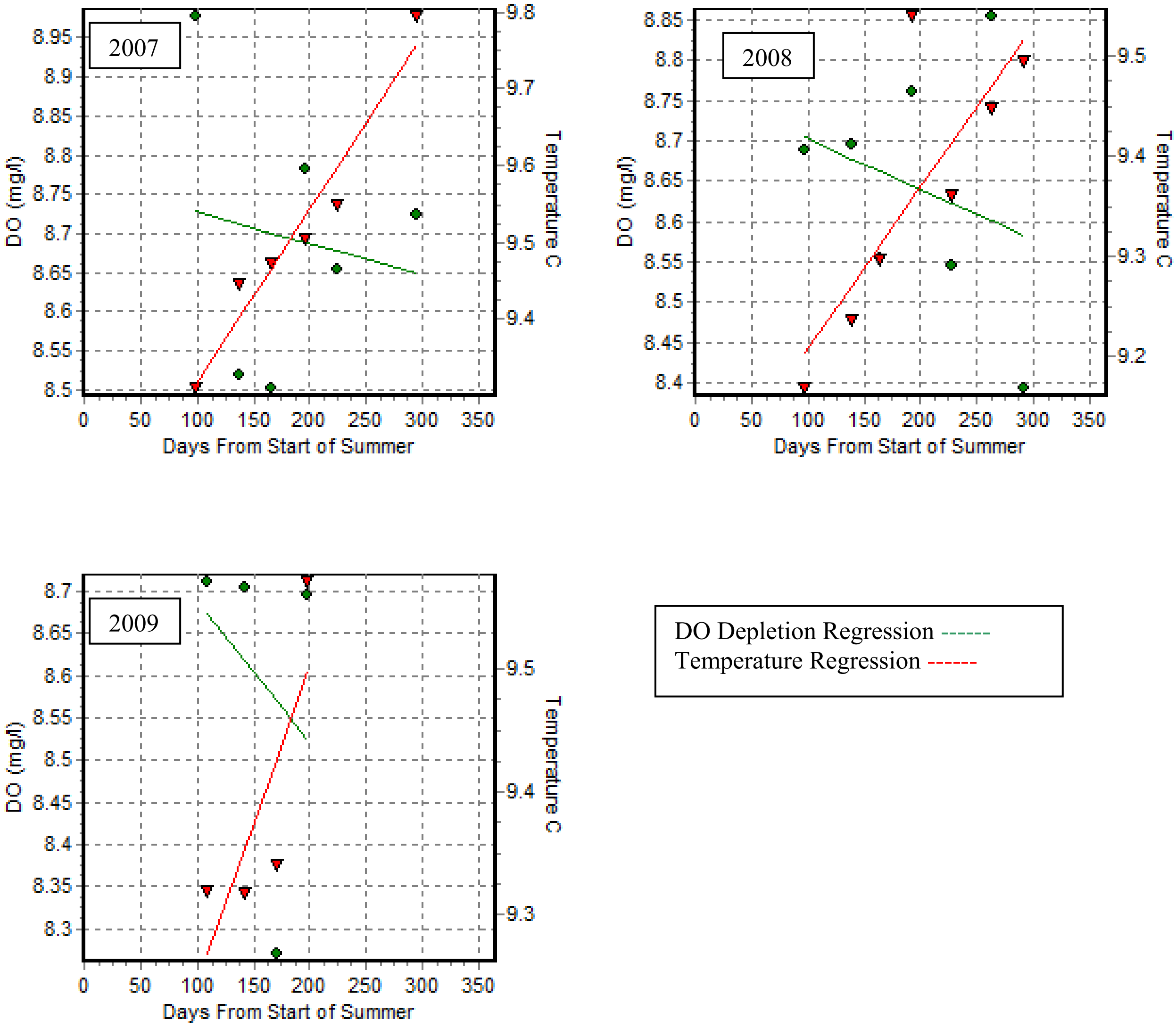

Figure 8.11 Seasonal DO and temperature plots for the calculation of HVOD rates for Lake Wanaka from 2007, 2008 and 2009

These values and the average hypolimnion temperatures during the periods of HVOD rate measurement are shown in Table 8.2. Since HVOD can be changed by temperature, the rates have been adjusted to a standard temperature to make them more comparable (Burns, 1995). The standard temperature chosen for Lake Wanaka was 9.5°C, as this results in minimum change in the rates when adjusting from observed values to temperature adjusted values. The temperature adjusted rates are also shown in Table 8.2.

Table 8.2 Observed and adjusted HVOD rates. Lake Wanaka 2006 to 2009

Summer	Average temp °C	Observed DO depletion rate °C (mg m^3 day-1)	Observed rate at 9.5°C (mg m^3 day-1)
2006/2007	9.513	0.408	0.408
2007/2008	9.363	0.622	0.627
2008/2009	9.637	1.675	1.689

Figure 8.12 shows that there was no significant trend in the HVOD rates from 2006 to 2009.

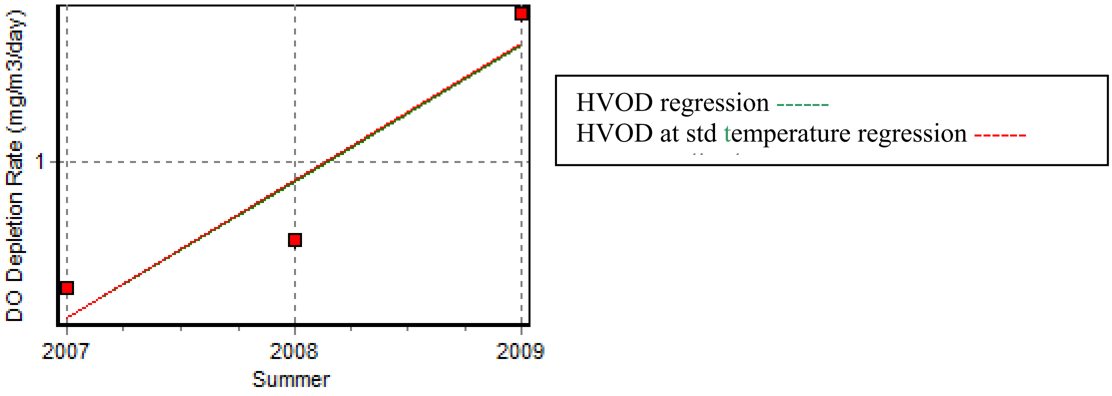

Figure 8.12 Plot of observed HVOD rate and the HVOD rate corrected to a standard hypolimnion temperature of 9.5°C for Lake Wanaka from 2006 to 2009

8.10 Percent Annual Change: Results

The PAC values are calculated using the annual change values obtained from the slopes of the four key variables (chla, secchi depth, TN and TP) that show significant change. This calculation is described in Appendix 2.

Only PAC values calculated from significant trend lines are considered indicative of change in a particular variable. Algal biomass at all three sites and total nitrogen in Roy's Bay were the only variables with significant slopes; otherwise the PAC values were replaced by a value of 0.00 (Table 8.3).

Table 8.3 PAC results for Lake Wanaka

	Chla (mg/m^3)	SD (m)	TP (mg/m^3)	TN (mg/m^3)
Dublin Bay				
Change - units per year	0.14	(0.72)	(0.00)	(17.43)
Average over period	0.46	(12.89)	(5.24)	(139.65)
Percent annual change (%/year)	30.43	0.00	0.00	0.00
Roy's Bay				
Change - units per year	0.10	1.32	(0.06)	28.20
Average over period	0.37	12.15	(5.72)	140.00
Percent Annual Change (%/year)	27.03	-10.86	0.00	20.14
Open water				
Change - units per year	0.08	(0.78)	(1.00)	(-4.88)
Average over period	0.48	(13.01)	(5.67)	(151.74)
Percent Annual Change (%/year)	16.67	0.00	0.00	0.00

The decision on whether a lake has changed over time is made by looking at the p-value of the PAC average. The PAC values for the three years of monitoring Lake Wanaka are shown in Table 8.4. All sites had a p-value of >0.3, which means that the lake did not change state over the monitoring period at any site (Table 8.4).

Table 8.4 Lake Wanaka: PAC averages and p-value

Site	PAC and p-value
Dublin Bay	PAC = 2.59 ± 7.74 % per year p-value = 0.76
Roy's Bay	PAC = 7.26 ± 7.04 % per year p-value = 0.36
Open Water	PAC = 3.33 ± 3.33 % per year p-value = 0.37

8.11 Trophic Level Index: Results

The TLI values are calculated next. This calculation is described in Appendix 2. The annual average values are taken from the three years of data shown in Table 8.5.

Table 8.5 Lake Wanaka: Average annual values for the four key variables

Period	Chla (mg/m^3)	SD (m)	TP (mg/m^3)	TN (mg/m^3)
Dublin Bay				
May 2006 - Apr 2007	0.28	12.55	7.48	114
May 2007 - Apr 2008	0.52	12.25	5.24	167.89
May 2008 - Apr 2009	0.58	13.88	5.08	141.58
Averages	0.46	12.90	5.93	141.16
Roy's Bay				
May 2006 - Apr 2007	0.24	11.1	6.05	108.1
May 2007 - Apr 2008	0.47	11.51	4.77	173.33
May 2008 - Apr 2009	0.45	13.89	6.25	152.14
Averages	0.39	12.17	5.69	144.52
Open water				
May 2006 - Apr 2007	0.41	12.4	4.76	145.29
May 2007 - Apr 2008	0.5	12.65	5.46	181.54
May 2008 - Apr 2009	0.55	14.01	6.81	134.38
Averages	0.49	13.02	5.68	153.74

The trophic level values for each of the variables and TLI values generated from these numbers are shown in Table 8.6, as are the average TLI values from the two most recent years of data.

Table 8.6 Lake Wanaka: Trophic level values derived from the average annual values

	TLc	TLs	TLp	TLn	TLI average
Dublin Bay					
May 2006 - Apr 2007	0.81	2.28	2.77	2.58	2.11
May 2007 - Apr 2008	1.51	2.32	2.32	3.09	2.31
May 2008 - Apr 2009	1.62	2.11	2.28	2.86	2.22
Averages	1.31	2.23	2.46	2.84	2.21
Roy's Bay					
May 2006 - Apr 2007	0.63	2.48	2.5	2.51	2.03
May 2007 - Apr 2008	1.38	2.42	2.2	3.13	2.28
May 2008 - Apr 2009	1.35	2.11	2.54	2.96	2.24
Averages	1.12	2.33	2.41	2.87	2.18
Open water					
May 2006 - Apr 2007	1.24	2.3	2.2	2.9	2.16
May 2007 - Apr 2008	1.44	2.27	2.37	3.19	2.32
May 2008 - Apr 2009	1.55	2.09	2.65	2.8	2.27
Averages	1.41	2.22	2.41	2.96	2.25

The average values for the clarity and nutrients fall into the same trophic category (oligotrophic) at each site; however, the average value for algal biomass falls into a lower trophic category (microtrophic).

Table 8.7 summarises the TLI value and TLI trend for each site.

Table 8.7 Lake Wanaka: TLI value and trend for each site

Site	TLI time trend
Dublin Bay	TLI value = 2.21 ± 0.18 TLI units TLI trend = 0.05 ± 0.24 TLI units per year p-value = 0.8227
Roy's Bay	TLI value = 2.18 ± 0.21 TLI units TLI trend = 0.10 ± 0.27 TLI units per year p-value = 0.7004
Open Water	TLI value = 2.25 ± 0.17 TLI units TLI trend = 0.06 ± 0.22 TLI units per year p-value = 0.8023

The TLI trend is in different units to the PAC value but is in qualitative agreement with it. The combined PAC and TLI trend information yields the conclusion that, at each site, Lake Wanaka is oligotrophic and not changing state.

8.12 Plots of other data (NNN, DRP, pH, DO, temperature)

Several variables other than those termed key variables were monitored as part of the programme. Figures 8.13 to 8.17 show plots of nitrite-nitrate nitrogen (NNN), dissolved reactive phosphorus (DRP) and pH. Turbidity and NH4 were not plotted as values at each site were always low. For each parameter, seasonal trend results are given. If any of the parameters show a significant trend over time, then these plots are also shown.

The last two figures (8.18 to 8.19) show plots of temperature and DO that demonstrate that the lake stratified during the monitoring period.

NNN is shown in Figure 8.13. All sites show minimum concentrations in late summer, peaking between September and November.

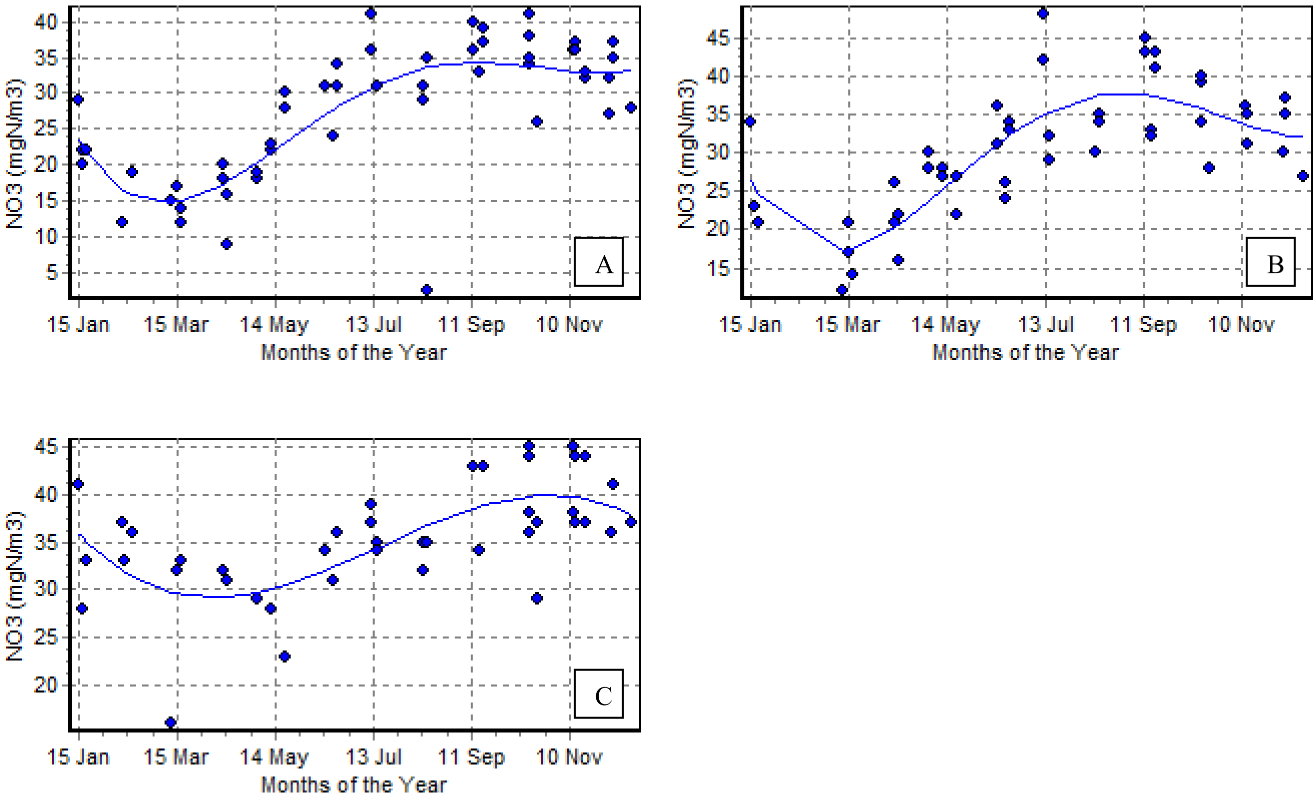

Figure 8.13 **Lake Wanaka: Epilimnetic nitrite-nitrate nitrogen plotted against month of year (A=Dublin Bay, B=Roy's Bay, C=open water)**

Figure 8.14 shows that Roy's Bay has a trend of decreasing NNN of 4.15 mg m^{-3} year^{-1}. The open water site shows a decrease of 0.07 mg m^{-3} year^{-1}. Dublin Bay did not show a trend.

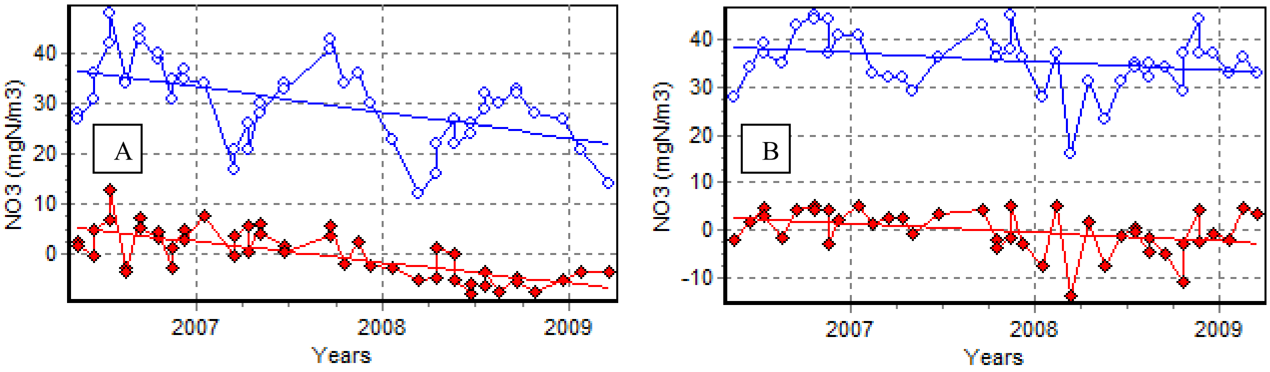

Figure 8.14 **Lake Wanaka: Plot of observed and deseasonalised time trends for nitrite-nitrate nitrogen (A= Roy's Bay, B=open water)**

Figure 8.15 shows the annualised data for DRP. It shows that there is very little variation in DRP throughout the year. Higher results tend to occur around September/October, but concentrations at each site are very low. There is no significant trend.

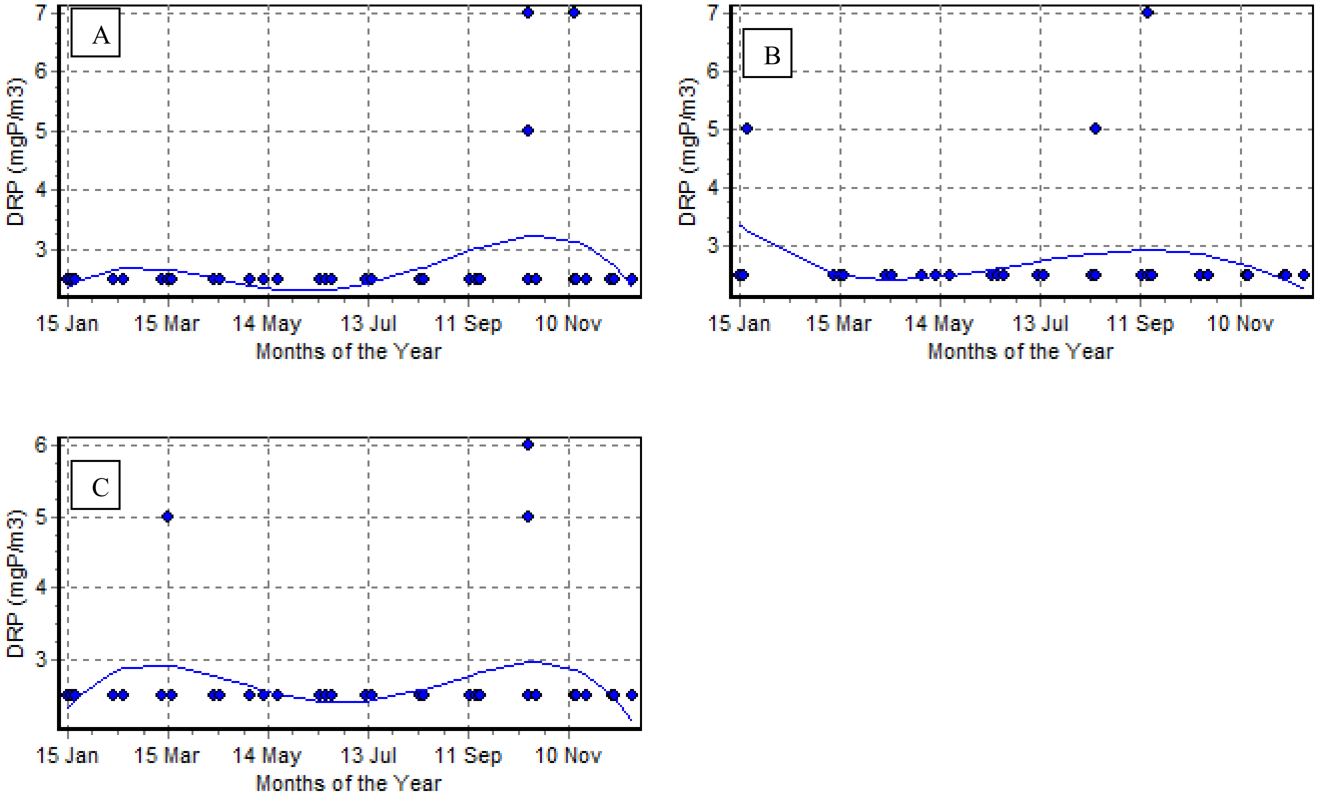

Figure 8.15 **Lake Wanaka: Epilimnetic dissolved reactive phosphorus plotted against month of year (A=Dublin Bay, B=Roy's Bay, C=open water)**

Figure 8.16 shows the pH conditions. There is a seasonal trend with the epilimnetic pH increasing in the summer months, probably as a result of some algal growth, but it also increases slightly during the winter.

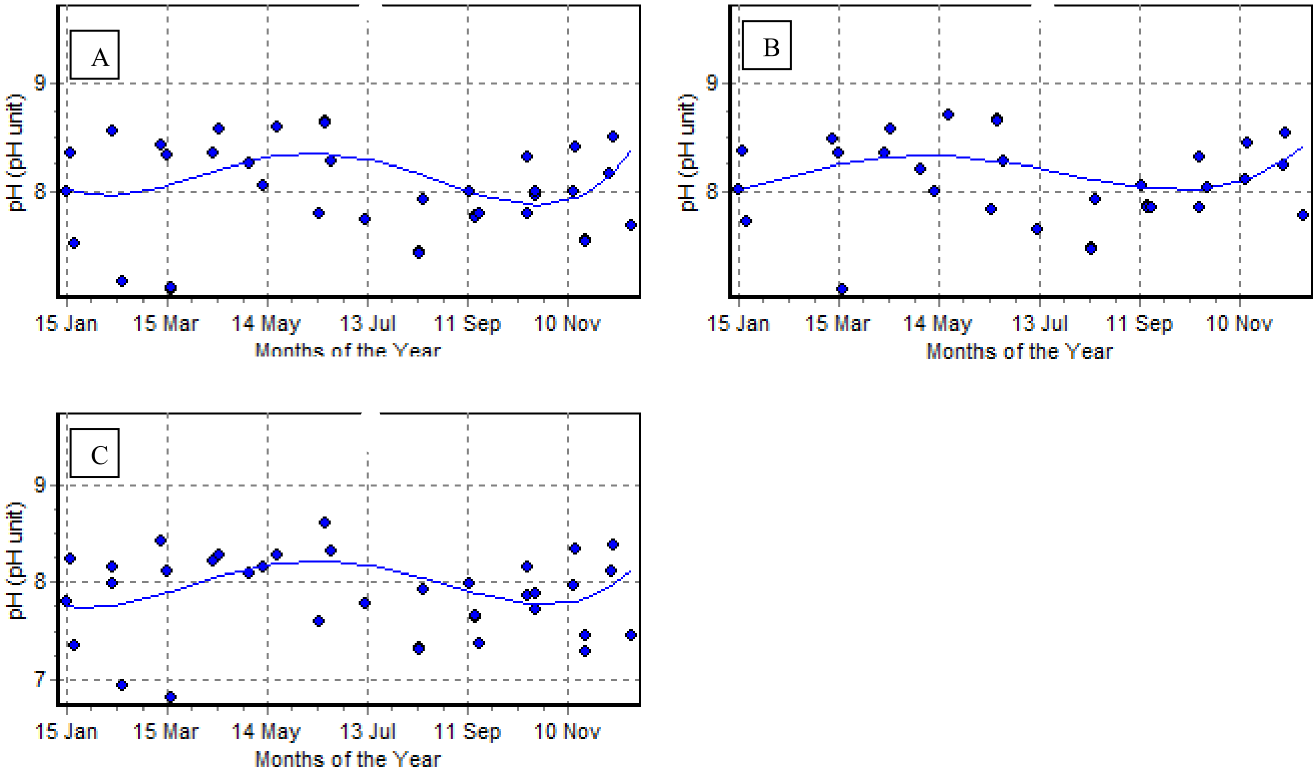

Figure 8.16 Lake Wanaka: Epilimnetic pH plotted against month of year (A=Dublin Bay, B=Roy's Bay, C=open water)

Figure 8.17 shows that dissolved oxygen concentrations are at their highest in autumn and winter. The low concentration of algae found in the lake means that there is no summer peak associated with algal blooms. The difference between winter and summer levels is purely temperature-related.

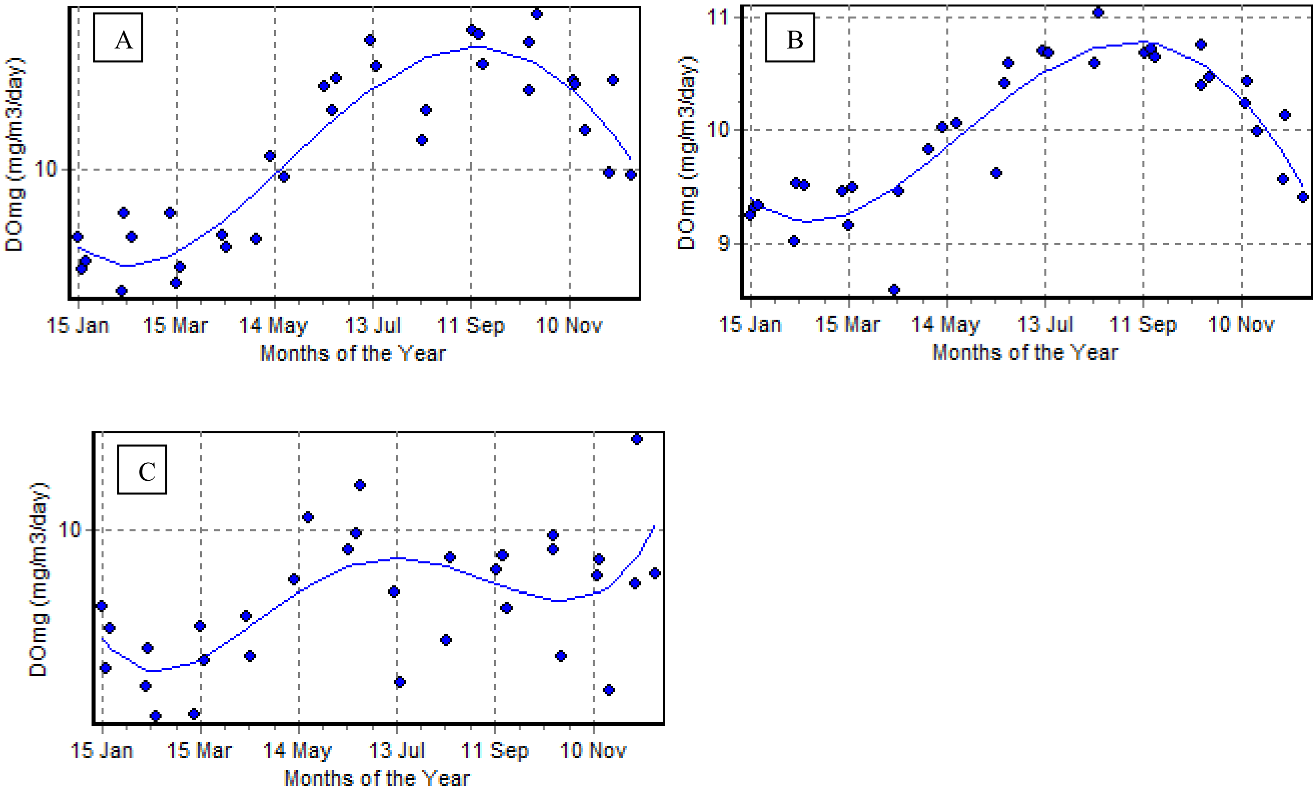

Figure 8.17 **Lake Wanaka: Epilimnetic dissolved oxygen plotted against month of year. (A=Dublin Bay, B=Roy's Bay, C=open water)**

Figure 8.18 shows depth profiles of dissolved oxygen at 20m and 130m; these were taken at monthly intervals throughout the year. The two lines of oxygen data do not meet. This implies that there may be incomplete reoxygenation of the hypolimnion each year.

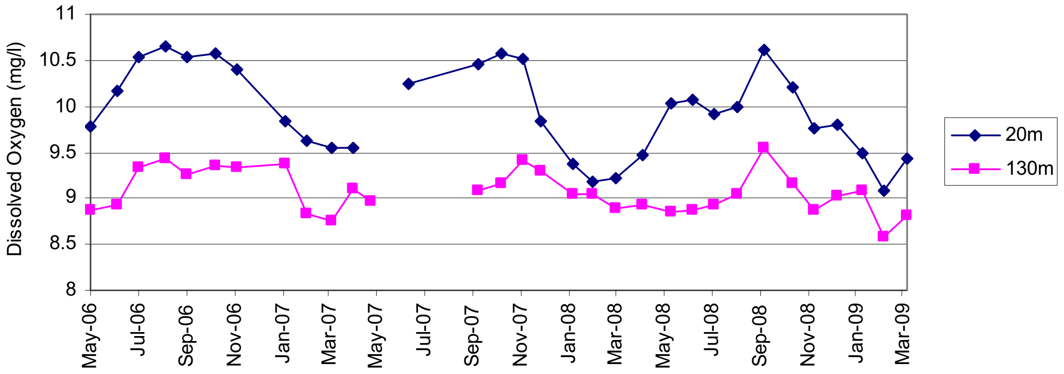

Figure 8.18 **Time series dissolved oxygen (mg/l) at 20m (pink) and 130m (blue) depths**

Figure 8.19 shows depth profiles of temperature measured at the open water site, taken at monthly intervals throughout the year. The two lines meet in late winter each year, indicating that there was complete mixing during the monitoring period.

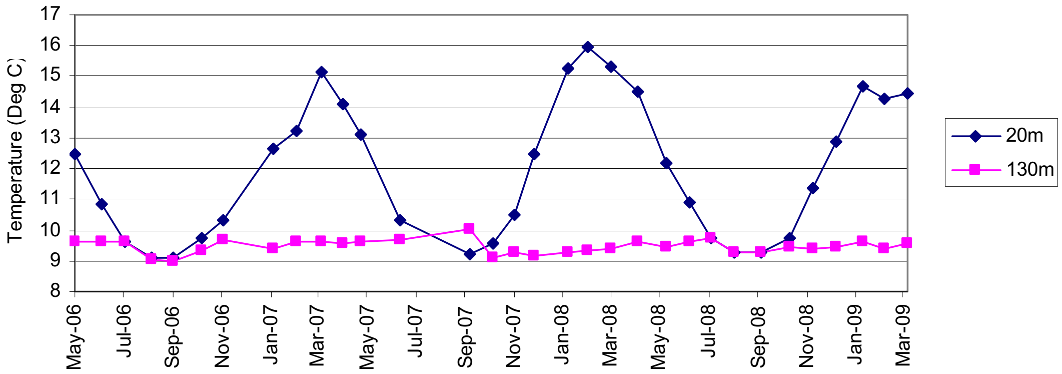

Figure 8.19 Time series temperature (°C) at 20m (pink) and 130m (blue) depths

8.13 Discussion

Lake Wanaka was monitored at three sites: Roy's Bay, Dublin Bay and an open water site. The size of Lake Wanaka relative to the percentage of modified catchment means that eutrophication of the open water is unlikely. However, the rapidly growing township of Wanaka lies on the shores of Roy's Bay, an enclosed arm with no natural outlet.

All the sites on Lake Wanaka were sampled on the same days; therefore, pairwise t-test comparisons for each site with all other sites were undertaken to determine differences in water quality indices between the sites. Of the twelve paired sites analysed, two were significantly different. These are shown in Table 8.8.

Table 8.8 Pairwise t-tests to test for differences in water quality between sites

		Chlorophyll a	Secchi depth	Total nitrogen	Total phosphorus
Roys Bay/open water	P-value	0.02	0.04	0.44	1.0
	Reject null hypothesis?	Yes	Yes	No	No
Dublin Bay/Roy's Bay	P-value	0.008	0.19	0.29	0.66
	Reject null hypothesis?	Yes	No	No	No
Open Water/Dublin Bay	P-value	0.30	0.33	0.06	0.69
	Reject null hypothesis?	No	No	No	No

The results from Roy's Bay and the open water site have significant differences between the clarity and algal biomass values. Figure 8.20 shows these differences.

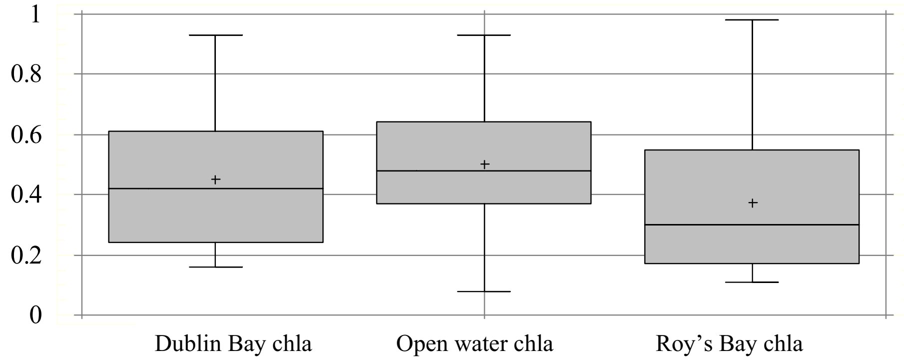

Figure 8.20 **Box and whisker plot of algal biomass (chla) at the three monitoring sites in Lake Wanaka. There are significant differences between Roy's Bay and the open water site ($p=>0.05$)**

The Roy's Bay site had significantly lower clarity than the open water site (Figure 8.21), but there was a significant trend of clarity increasing by 1.31m year^{-1} (Figure 8.8). There was no significant trend in Dublin Bay or the open water site.

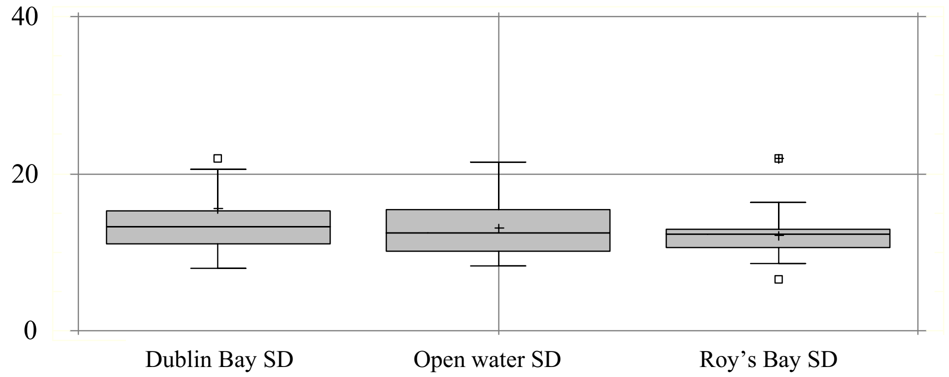

Figure 8.21 **Box and whisker plots of clarity (secchi depth) at the three monitoring sites in Lake Wanaka. There are significant differences between Roy's Bay and the open water site ($p=>0.05$)**

With increasing water clarity, the corresponding trend we would expect to see is one of decreasing algal biomass. This was not observed: Roy's Bay and Dublin Bay showed a significant increase in chla concentrations over the monitoring period. Roy's Bay shows an increase of 0.1 mg m-^{3} year-^{1} and Dublin Bay 0.13 mg m-^{3} year-^{1} (Figure 8.7). It is likely that weather conditions dictated the observed significant trend in clarity in Roy's Bay. Roy's Bay also had higher TP concentrations than the other two sites (Figure 8.22).

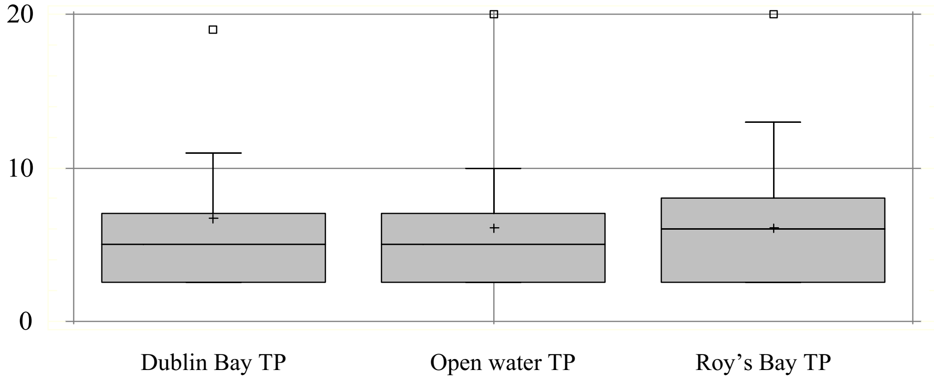

Figure 8.22 Box and whisker plots of TP concentrations (mg/m3) at the three monitoring sites in Lake Wanaka

Figure 8.10 shows that TN is increasing in Roy's Bay at a rate of 28.2 mg m^{-3} $year^{-1}$ (p-value = 0.009). Dublin Bay and the open water site do not show a significant trend.

Analysis of the non-key variables showed that Roy's Bay had a significant declining trend in nitrite-nitrate nitrogen (-4.1 mg m^{-3} $year^{-1}$), however no other significant trends in dissolved oxygen, pH, turbidity or dissolved reactive phosphorus were found. A lack of trends in these variables and any strong trends in the key variables indicate that the lake is in a relatively stable state.

Roy's Bay has more variable water quality than the other two sites, but all the sites have low levels of total nitrogen, total phosphorus and algal biomass, and all the sites have high water clarity. This is suggestive of a system with little catchment modification.

Average levels of nutrients and clarity are consistently indicative of an oligotrophic state whereas levels of algal biomass are more in line with a lower trophic level and fall into the microtrophic category. Overall lake water quality is classified as oligotrophic. Average PAC values indicate that there has been no change in the overall lake water quality since 2006.

8.14 Conclusion

The monitoring between 2006 and 2009 shows that Lake Wanaka appears to be in a stable state, with little change in water quality occurring over the last three years. It can currently be classified as being in an oligotrophic state, although chla falls into the microtrophic category.

Analysis of key variables showed a trend of increasing algal biomass at all three sites. Roy's Bay also shows a trend of increasing clarity and total nitrogen. Rates of change are, however, extremely slow and it is unlikely to have any biological significance.

A water body's trophic state is largely determined by nutrient inputs from the surrounding catchment (Barnes, 2002). The major inputs into Lake Wanaka are the Makarora and Matukituki Rivers, both of which have glacial origins and high water quality. The immediate catchment is likely to contribute some nutrient input into the lake i.e. stormwater from the township of Wanaka and runoff from fertilised agricultural areas. Of the three sites, Roy's Bay is most at risk of deteriorating water quality due to the proximity of Wanaka township. Roy's Bay also has no natural outlet and therefore a lack of throughflow.

In summary, TLI values have been established for Lake Wanaka. It is classified as oligotrophic at all three sites and PAC values conclude that the TLI status is stable.

9. References

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10. Appendices

Appendix 1

Water Quality Monitoring Parameters

List of variables routinely monitored in the ORC Lakes Water Quality Monitoring Programme

Parameter	Description
Dissolved oxygen	A measure of the life supporting capacity of a waterbody, influenced by atmospheric transfer, respiration, photosynthesis and temperature. DO concentrations can also regulate the release of bioavailable nutrients from sediments.
Temperature	Organisms can only tolerate a particular range of temperatures. Outside of this range metabolic rates can be affected. Temperature profiles are a useful measure of the annual pattern of stratification many lakes exhibit. Separate layers of water can develop in warm calm conditions that exhibit different physical and chemical characteristics. All these factors can impact the life supporting capacity of water.
Conductivity	A measure of the total soluble salt content of water. Salt content is an important influence on the biota that can inhabit an ecosystem.
pH	Indicates the acid/alkaline state of water. Natural freshwaters normally have a pH approaching neutrality (7), although the accepted range for most biota is 6 – 9. High pH mobilises toxic compounds, which may potentially affect aquatic organisms.
Nutrients (N and P)	Nitrogen and phosphorus are essential elements for plant growth. When found in high quantities of their bio-available form, excessive growths of algae may result, degrading water quality.
Chla	An indirect measure of photosynthetic algae abundance
Turbidity & suspended solids	Provides a measure of the level of material suspended in the water column potentially available to scatter light and reduce water clarity. High turbidity and suspended solids can reduce the productivity of a waterbody and interfere with the respiration organs of some aquatic biota.

Identifier (and unit), parameter and method

Identifier	**Parameter**	**Method**
DO (ppm)	Dissolved oxygen	Hand-held meter (Hydrolab DS5X)
DO (% sat)	Dissolved oxygen	Hand-held meter (Hydrolab DS5X)
Temp (Deg C)	Temperature	Hand-held meter (Hydrolab DS5X)
Cond @ 25 ° (mS/m)	Conductivity	Hand-held meter (Hydrolab DS5X)
Sal (g.m-^{3})	Salinity	Hand-held meter (Hydrolab DS5X)
pH	pH	Hand-held meter (Hydrolab DS5X)
SS (g.m-^{3})	Suspended solids	APHA (1998) 2540 D
Turb (NTU)	Turbidity	Hand-held meter (Hydrolab DS5X)
SD (m)	Secchi disk	Secchi disk
NH4-N (gN.m-^{3})	Ammoniacal nitrogen	APHA (1998) 4500-NH3 G
NNN gN.m-^{3}	Nitrate/Nitrite nitrogen	APHA (1998) 4500-NO3 F
TN (g.m-^{3})	Total nitrogen	APHA 4500-NO3 F. 4500-N C.
DRP (g.m-^{3})	Dissolved reactive phosphorus	APHA (1998) 4500-P F
TP (g.m-^{3})	Total phosphorus	NWASCO method 8
Chla	Chla	Hand-held meter (Hydrolab DS5X)
E. coli (cfu/100ml)	Escherichia coli	APHA (Water) 9230 confirmation by NA-MUG, APHA 9222G

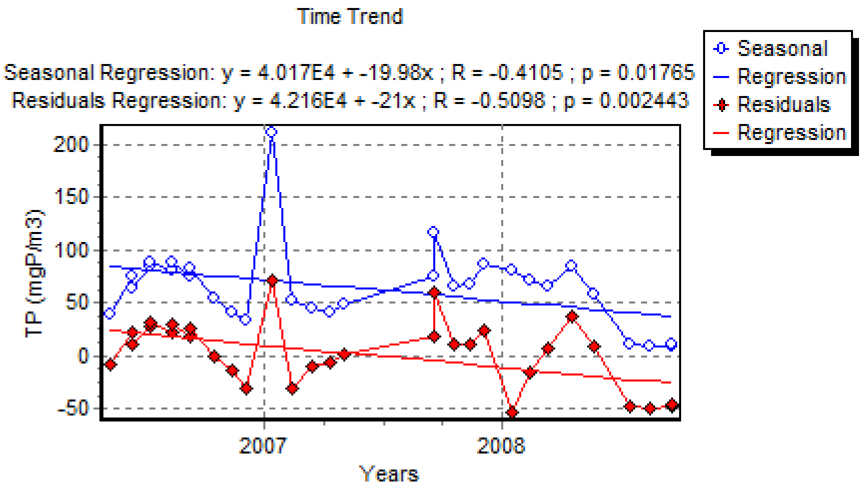
Appendix 2

Percent Annual Change (PAC)

PAC is the average annual rate of change of clarity, algae and nutrients.

PAC is calculated by plotting the data as a function of month with no regard to the year of collection. A polynomial curve is then fitted to these data which allows for the deseasonalised residuals to be calculated. The observed and deseasonalised residuals are then plotted against time, and straight line plots are fitted using ordinary least squares regression. The slope of the time trend is divided by the average value of the variable during the period of its observation.

To illustrate PAC, an example from Lake Johnson is used. The graph below shows the annual change in TP for Lake Johnson is -21 mg m^{-3} year^{-1}, with a p-value of 0.002. This negative value indicates a decline in phosphorus. When this is divided by the averge concentration for the period of 61.94 mg m^{-3}, a PAC value of -33.9% year^{-1} is obtained. Only PAC values calculated from significant trend lines are considered indicative of change in a lake PAC values calculated from non-significant slopes are replaced by a value of 0.0. The PAC values for the different variables are expressed in the same units (% change per year) and thus can be added together. They are then averaged and a p-value obtained for this average. The PAC values for Lake Johnson were 48.16 (chla), 27.15 (secchi depth), -33.9 (TP) and -24.42 (TN). The average of these values is 3.40 with a p-value of 0.84.



Lake Johnson plot of observed and deseasonalised time trends for total phosphorus

The decision on whether a lake has changed over time is made by examining the p-value of the PAC average. A p-value of less that 0.1 interprets as definite change, a p-value of between 0.1 and 0.2 means probable change, a p-value of between 0.2 and 0.3 means possible change and a p-value of more than 0.3 means no change.

As the p-value for Lake Johnson is 0.84, the interpretation is that there has been no change of the monitoring period.

The PAC value is thought to be better than the TLI time trend value in deciding whether a lake has changed trophic level, because it utilises up to five variables and the data are not condensed to a few numbers before analysis. The observed and residual data plots allow for a good look at the actual data obtained for analysis, which is not possible when annual averages are used. However, while PAC values give a good indication that change may be happening, it is only a relative measure and difficult to utilise.

Trophic Level Index (TLI)

The TLI classifies the actual state of a lake at a specific time and changes over time can be calculated from the slope of the regression line. Burns et. al. (2000*a*) determined that the following equations would give individual trophic values for chla (TLc), secchi depth (TLs), total nitrogen (TLn) and total phosphorus (TLp):

- $TLc = 2.22 + 2.54 \log (chla)$
- $TLs = 5.56 + 2.60 \log ({}^{1}/_{SD} - {}^{1}/_{40})$
- $TLp = 0.218 + 2.92 \log (TP)$
- $TLn = -3.61 + 3.01 \log (TN)$

The mean of these individual trophic values then gives the trophic level index (TLI) for each lake:

- $TLI = \Sigma\ (TLc + TLs + TLp + TLn)/4$

The equations normalise the annual average values of chla, SD, TP and TN, allowing comparison between variables (i.e. TLn significantly lower than TLp indicates the lake is N-limited) and with other lakes, following the lake classification system in Table 5.1 (Burns et al. 2005). The higher the TLI, the lower the water quality.

HVOD

Observed HVOD rates are given by the slopes of the equations to the DO depletion rate trend lines. Since HVOD rates can be changed by temperature, it is better to use HVOD rates that are adjusted to a standard temperature to make them more comparable (Burns, 1995) from year to year. The temperature chosen results in minimum change in the rates when adjusting them from the observed values to temperature-adjusted values. The equation used in adjusting the rates (Burns, 1995) is:

$$HVOD_{std} = HVOD_{obs} 1.0718^{(Tstd-Tobs)}$$

Where $HVOD_{obs}$= HVOD rate at observed temperatures

$HVOD_{std}$= HVOD rate at standard temperatures

Appendix 3

Sample Results

Lake Hayes

Lake Johnson

Lake Onslow

Lake Wakatipu

Lake Wanaka

Lake Hayes: Sample results

Lake: Lake Hayes Station: Buoy

Date	Depth	TP mg/m^3	TN mg/m^3	Chla mg/m^3	NO3 mg/m^3	NH4 mg/m^3	DRP mg/m^3	Turb NTU	pH
11/05/2006	21	45	280	15.62	2.5	5	7		7.86
	23	142	390	0.55	2.5	170	102		7.12
	27.5	305	650	0.44	2.5	520	218		7.12
13/06/2006	8.2	81	400	14.57	2.5	10	32	2.31	7.79
11/07/2006	24.6	62	550	15.04	2.5	10	29	1.22	7.88
	8.2	67	420	18.49	8	10	29	2	7.91
14/08/2006	24.9	53	340	13.15	2.5	5	24	2.6	7.89
	8.3	56	250	17.34	2.5	10	19	2.6	7.92
11/09/2006	24.9	30	290	2.63	2.5	20	11	1.6	7.89
	8.3	51	520	25.75	7	20	14	4.1	8.24
16/10/2006	17	53	440	17.42	2.5	5	12	2.95	8.98
	29	32	290	1.05	5	80	18	2.5	7.88
13/11/2006	12	67	530	37	2.5	10	2.5	5.8	9.84
	24.1	21	170	1.49	2.5	10	10	1.8	7.75
06/12/2006	17	76	630	76.3	2.5	10	6	15	10.08
	27.1	29	310	2.46	2.5	10	12	0.7	7.57
14/01/2007	4	154	900	81.5	2.5	10	2.5	16.4	10.19
	20.7	96	210	0.29	2.5	30	38	0	7.48
	25.1	114	220	0.29	2.5	40	26	0	7.1
13/02/2007	6.6	56	480	20.5	7	10	5	6.5	9.91
	21.2	107	310	0.3	2.5	80	72	0	7.29
16/03/2007	14	64	470	22.1	2.5	10	5	4.5	8.85
	24.5	140	390	0.34	2.5	180	75	0	7.27
11/04/2007	13.5	69	510	22.6	2.5	5	2.5	4.4	8.71
	26.3	216	520	0.31	2.5	360	148	0	7.36
02/05/2007	19	66	400	21.9	2.5	5	6	5.45	8.06
	27	157	510	0.45	2.5	300	64	1.6	7.44
20/06/2007	8.1	77	430	10.8	7	80	36	0.6	7.98
	24.9	69	400	10.67	6	80	36	1.17	8
19/09/2007	24.9	50	600	0.52	26	150	24	0	7.68
	8.3	41	340	3.09	32	70	14	0	8.11
18/10/2007	21.8	31	540	0.47	16	110	19	1.16	7.71
	7.3	42	600	19.79	16	50	10	1.7	8.43
12/11/2007	23.6	29	460	0.38	22	150	12	2.29	7.62
	7.8	22	420	8.41	18	240	13	0	8.63
04/12/2007	2.1	66	890	32.6	2.5	5	2.5	16.7	10.22
	20.7	15	280	5.94	11	5	5	0	7.55
18/12/2007	23	25	430	0.31	26	100	13	0	7.77
	5.8	34	210	85.7	2.5	5	2.5	12.95	10.12
07/01/2008	23.5	41	510	0.29	194	5	22	0	7.54
	2.5	98	1230	83.4	2.5	5	2.5	12	10.27
16/01/2008	3.3	34	630	28.8	2.5	10	2.5	1.95	9.93
	20.8	27	320	0.32	100	5	15	0	7.73
	29.1	90	630	0.32	141	220	40	1.58	7.62
31/01/2008	3.2	77	800	53.4	2.5	5	2.5	7.9	9.93

Lake: Lake Hayes Station: Buoy

Date	Depth	TP mg/m^3	TN mg/m^3	Chla mg/m^3	NO3 mg/m^3	NH4 mg/m^3	DRP mg/m^3	Turb NTU	pH
	19.8	52	330	0.3	32	5	27	0	7.68
	19.9	67	370	0.3	66	20	39	0	7.61
11/02/2008	5.8	64	670	19.5	2.5	10	2.5	2.45	9.83
	20.1	70	270	0.33	2.5	30	32	0	7.66
28/02/2008	5.54	57	640	18.5	2.5	5	2.5	1.55	9.77
	20.6	83	300	0.39	2.5	80	52	0	7.68
10/03/2008	12.5	63	650	23.3	2.5	5	2.5	2	9.27
	23.2	135	420	0.38	2.5	150	72	0	7.7
03/04/2008	26.4	151	500	0.39	5	240	139	0	7.81
	12.3	42	510	26.7	5	5	28	2.7	9.36
14/04/2008	13.6	64	560	45.3	2.5	10	6	5.45	8.94
	23	147	510	0.39	2.5	220	82	0	7.82
01/05/2008	17.8	60	580	22.7	2.5	5	2.5	1.7	8.44
	25.9	191	610	0.38	5	350	97	0	7.93
19/05/2008	20.4	54	400	22.2	2.5	5	11	0.7	8.29
	28.6	234	800	0.44	7	460	114	0	7.87
19/06/2008	23.9	82	450	19.1	2.5	5	20	1	8.51
	7.9	78	520	14.5	2.5	5	23	0.5	8.52
14/07/2008	7.9	74	570	15.68	11	70	21	1.48	9.34
	24	65	480	16.1	14	70	22	1.72	9.33
12/08/2008	7.9	62	480	34.82	14	40	9	1.81	7.44
	24	60	470	35.01	15	50	11	1.59	7.4
15/09/2008	7.9	33	400	7.17	2.5	5	5	1.1	8.27
	24	36	460	11.95	5	70	8	1.03	7.57
21/10/2008	8	37	550	11.89	5	5	5	1.54	8.31
	24	37	430	0.46	7	190	27	1.24	7.52
19/11/2008	8	28	560	13.87	2.5	20	7	1.21	8.5
	24	43	590	0.41	8	250	29	0.67	6.76
08/12/2008	24.5	44	480	0.54	11	220	25	2.08	6.71
	3.3	60	800	42.27	2.5	5	2.5	3.84	9.06
05/01/2009	24.5	126	590	0.38	2.5	160	66	1.84	6.79
	20.6	66	290	1.28	2.5	20	31	1.19	6.85
	7.2	57	620	56.3	2.5	5	5	3.69	9.4
19/01/2009	22	95	340	0.29	2.5	100	71	0.79	6.96
	4	60	590	30.61	2.5	5	6	7.33	9.57
02/02/2009	10.8	95	680	45.55	2.5	5	5	4	8.87
	23	165	470	0.33	2.5	210	94	0.75	6.97
16/02/2009	25.1	130	400	0.32	2.5	210	101	1.95	6.39
16/02/2009	12	68	550	38.97	2.5	5	2.5	9.07	8.31
02/03/2009	23	168	560	23.17	2.5	300	126	1.03	6.65
	9.3	71	650	42.06	2.5	5	6	4.65	8.32
16/03/2009	26.6	168	600	0.35	2.5	370	145	1.09	6.33
	4.1	55	940	12.35	11	10	2.5	3.36	7.84
31/03/2009	14	86	640	22.41	7	5	2.5	2.61	7.18
	24.7	164	560	0.35	2.5	270	119	0.95	6.32
21/04/2009	0	82	530	31.16	5	5	7	3.02	8.01
	24.7	187	620	0.34	2.5	390	149	1.83	7.57

Lake Hayes: Secchi depth (m)

Date	Secchi depth	Date	Secchi depth	Date	Secchi depth	Date	Secchi depth
11/05/2006	3.5	02/05/2007	3.3	10/03/2008	3.4	17/12/2008	2.2
13/06/2006	4	20/06/2007	6.4	03/04/2008	3.2	05/01/2009	2.1
11/07/2006	4	19/09/2007	3.15	14/04/2008	2.5	19/01/2009	2.1
14/08/2006	4.4	18/10/2007	3.5	01/05/2008	2.9	02/02/2009	1.9
11/09/2006	3.5	12/11/2007	1.7	19/05/2008	3.5	16/02/2009	2
16/10/2006	2.9	04/12/2007	1.5	19/06/2008	3.2	02/03/2009	1.9
13/11/2006	3.9	18/12/2007	1.55	14/07/2008	3.4	16/03/2009	3.1
06/12/2006	2.7	07/01/2008	1.4	12/08/2008	1.9	31/03/2009	2.9
14/01/2007	1.6	16/01/2008	3	15/09/2008	3.9	21/04/2009	3.0
13/02/2007	3.1	31/01/2008	1.5	21/10/2008	3.7		
16/03/2007	3.1	11/02/2008	2.8	19/11/2008	2.2		
11/04/2007	2.7	28/02/2008	3.3	08/12/2008	2.2		

Lake Johnson: Sample results

Lake: Lake Johnson Station: Middle

Date	Depth	TP mg/m^3	TN mg/m^3	Chla mg/m^3	NO3 mg/m^3	NH4 mg/m^3	DRP mg/m^3	Turb NTU	pH
11/05/2006	21.5	191	1130	0.66	2.5	600	156		7.04
	13.5	40	600	1.99	2.5	5	10		7.89
13/06/2006	20.4	75	350	3.54	2.5	5	30	1.8	7.7
	6.8	64	700	3.45	2.5	70	47	1.68	7.69
11/07/2006	20	85	810	3.23	2.5	180	68	0.53	7.51
	6	89	840	3.32	2.5	190	68	0.82	7.52
14/08/2006	7	88	930	2.12	2.5	190	56		7.58
	21	81	830	2.17	2.5	190	44		7.55
11/09/2006	21.6	76	760	1.06	7	200	60		7.74
	7.2	82	930	4.01	9	120	43		8.11
16/10/2006	8	54	710	6.26	6	5	25	1	9.73
	20	96	860	1.78	10	270	82	0.1	7.96
13/11/2006	9	42	590	1.87	9	20	22	0.4	9.58
	25.3	173	980	0.82	10	600	146	0	7.53
06/12/2006	10	33	700	1	5	5	12	0.2	9.06
	22.5	168	1130	0.51	13	490	142	0	7.71
14/01/2007	26.7	229	1430	0.63	2.5	950	184	0	6.93
	7.3	211	790	13.11	2.5	5	2.5	2.2	9.05
	20.3	150	1050	0.73	19	410	112	0	7.96
13/02/2007	6	53	820	19.49	2.5	10	2.5	6.5	9.55
	19.4	149	1000	0.38	35	400	134	0	7.15
16/03/2007	9	46	1230	19.43	2.5	20	2.5	4.6	8.85
	19.75	156	1040	0.45	81	390	113	0	7.09
11/04/2007	20.4	204	2030	0.52	2.5	740	179	1.3	7.22
	10.5	42	850	14.31	2.5	5	2.5	3.35	8.55
02/05/2007	10	49	670	21.02	2.5	5	2.5	5.7	8.3
	21.6	169	1070	0.63	6	600	148	4	7.29
20/06/2007	7	172	1130	0.83	2.5	680	173	0	7.49
	21.2	56	610	11.34	2.5	5	29	1.4	7.98
19/09/2007	7.2	75	670	0.81	7	90	41		7.57
	21.3	117	1000	4.9	2.5	5	34		8.03
18/10/2007	9.1	65	790	3.13	2.5	20	40	0.05	8.06
	20.5	74	720	0.62	7	160	68	0	7.45
12/11/2007	21	89	830	0.54	2.5	5	2.5	0	7.33
	5.6	67	970	11.44	2.5	5	14	0.35	9.04
04/12/2007	20.9	101	840	0.43	23	240	84	0	7.38
	5.7	87	1090	21.33	2.5	5	6	4.45	9.69
16/01/2008	17.1	108	830	0.62	19	240	95	0	7.69
	23.9	171	1180	0.75	2.5	600	148	0.54	7.59
	5.2	81	1110	33.61	2.5	5	2.5	7.6	9.85
11/02/2008	5.3	71	1040	33.9	2.5	10	2.5	5.8	9.61
	16.8	104	850	0.6	47	190	83	0	5.4
10/03/2008	18.3	128	1040	0.62	44	310	113	0	7.6
	23.2	195	1420	5.39	2.5	830	177	0.48	7.7
10/03/2008	7.3	66	1000	32.62	2.5	5	2.5	5.35	8.97
14/04/2008	19.7	139	1000	0.62	6	450	116	0	7.68

Lake: Lake Johnson Station: Middle

Date	Depth	TP mg/m^3	TN mg/m^3	Chla mg/m^3	NO3 mg/m^3	NH4 mg/m^3	DRP mg/m^3	Turb NTU	pH
	8.6	84	1130	34.03	2.5	5	2.5	12	8.84
19/05/2008	13.3	59	750	8.42	5	5	9	4.1	8.43
	21.5	162	1220	5.49	2.5	660	138	0	7.89
14/07/2008	20.5	11	95	10.1	3	16	5.1	1.95	9.05
	6.8	10.9	95	13.6	0.6	16	5.5	2.17	9.06
12/08/2008	6.8	10	87	8.89	0.25	22	5.9	2.01	7.03
	20.5	9.8	89	9.07	0.25	22	6.1	1.86	7.07
15/09/2008	20.5	9.5	85	1.1	0.6	13	6.1	1.05	7.29
	6.8	10.9	91	10.03	0.5	28	7.8	1.08	7.68
21/10/2008	20.5	103	950	0.71	7	330	89	0.99	7.28
	6.8	64	950	3.54	5	5	43	0.55	8.56
19/11/2008	2.8	71	850	19.22	2.5	5	16	2.07	9.01
	19.4	121	1010	0.57	2.5	370	103	0.63	6.64
08/12/2008	24.75	153	1150	0.5	5	540	133	1.42	6.63
	1.8	75	950	30.3	2.5	5	6	7.24	9.41
17/12/2008	26.4	157	1150	0.4	2.5	550	134	0.57	6.72
	3.25	64	930	19.11	2.5	5	2.5	3.98	9.29
05/01/2009	22.2	152	1200	0.49	2.5	480	126	0.61	6.69
	2.8	70	1010	35.79	2.5	5	2.5	4.93	9.23
19/01/2009	2.05	72	950	21.3	2.5	5	2.5	7.36	9.25
	16.6	139	1060	0.49	5	530	133	0.69	6.71
02/02/2009	17.5	188	1180	0.49	2.5	590	137	0.43	6.74
	2.75	116	1020	29.15	2.5	5	2.5	4.18	8.85
16/02/2009	3.4	68	840	27.11	2.5	5	2.5	10.2	8.17
	18.2	156	1080	0.46	2.5	630	142	0.62	6.21
02/03/2009	1.9	66	980	34.39	2.5	5	2.5	4.89	8.18
	18.5	159	1200	0.46	2.5	570	133	0.46	6.45
16/03/2009	18.8	145	1270	0.47	2.5	640	143	0.55	6.18
	2.65	31	900	14.01	2.5	5	2.5	3.78	7.92
31/03/2009	22.6	180	1270	0.46	2.5	770	162	0.33	6.09
	4.35	75	900	24.57	2.5	5	2.5	4.07	7.24
21/04/2009	4.15	94	98	35.36	5	5	7	3.02	8.36
	19.3	164	1230	0.48	2.5	390	149	1.83	7.36

Lake Johnson: Secchi depth (m)

Date	Secchi depth	Date	Secchi depth	Date	Secchi depth	Date	Secchi depth
11/05/2006	5.5	16/03/2007	2.8	10/03/2008	1.9	05/01/2009	2
13/06/2006	8.65	11/04/2007	3.3	14/04/2008	1.8	19/01/2009	1.8
11/07/2006	7	02/05/2007	3.8	19/05/2008	2	02/02/2009	1.7
14/08/2006	6	20/06/2007	3.95	14/07/2008	3.8	16/02/2009	1.7
11/09/2006	6.2	19/09/2007	4.4	12/08/2008	3.4	02/03/2009	2
16/10/2006	3.8	18/10/2007	5.8	15/09/2008	2.7	16/03/2009	3.4
13/11/2006	4.9	12/11/2007	3.9	21/10/2008	5.2	31/03/2009	2.4
06/12/2006	8.3	04/12/2007	1.9	19/11/2008	2.1	21/04/2009	2.5
14/01/2007	4.7	16/01/2008	1.5	08/12/2008	2.2		
13/02/2007	2.8	11/02/2008	2	17/12/2008	2.3		

Lake Onslow: Sample results

Lake Onslow Station: Boat ramp

Date	TP mg/m^3	TN mg/m^3	Chla mg/m^3	NO3 mg/m^3	NH4 mg/m^3	DRP mg/m^3	Turb NTU	pH
26/05/2004	47	410		145	30	2.5	5.5	6.82
15/07/2004	46	420		155	30	6	8.1	6.43
17/11/2004	29	300		13	20	2.5	4.1	7.1
26/01/2005	29	290		8	20	2.5	2.6	6.86
15/03/2005	27	370		27	20	2.5	3	6.9
25/05/2005	26	130		28	30	2.5	2.8	6.93
28/07/2005	26	200		2.5	5	2.5	3	6.1
28/09/2005	22	220		7	5	2.5	2.5	6.73
24/11/2005	33	240		2.5	5	2.5	2.6	7.4
02/02/2006	36	280		2.5	20	5	2.8	6.76
29/03/2006	29	370		2.5	20	5	2.69	6.2
31/05/2006	24	250	1.9	7	5	2.5	2.12	6.98
03/08/2006	19	210	1.9	6	5	10	1.42	6.7
21/09/2006	26	210	1.3	2.5	10	7	3.35	7.69
23/11/2006	47	270		2.5	10	2.5	6.41	7.6
25/01/2007	20	220	3.6	2.5	20	8	2.32	7
21/03/2007	74	460	1.3	2.5	5	19	7.14	7
23/05/2007	86	460	3.8	2.5	10	13	19.7	6
25/09/2007	19	210	3.8	8	5	34	3.16	7.34
27/11/2007	25	250		2.5	5	2.5	3.9	7.2
30/01/2008	158	630	5.5	2.5	5	6	8.6	6.6
15/04/2008	27	280	2.9	2.5	5	2.5	2.75	6.8
03/06/2008	61	380		2.5	5	2.5	8.87	7.57
18/09/2008	44	250	3.4	6	5	5	8.28	5.8
16/10/2008	35	210	3.4	2.5	10	9	7.26	5.76
19/11/2008	43	240	3.1	2.5	5	2.5	6.85	6.6
04/12/2008	46	330	1.9	6	5	2.5	7.91	6.7
22/01/2009	41	290	2.5	5	5	6	4.45	5.9
17/02/2009	39	250		2.5	5	2.5	7.79	6.7

Lake Wakatipu: Historical sample results: 1952 to 1998

Date	Site	Secchi depth (m)	Chla (mg/m^3)	TP (mg/m^3)	TN (mg/m^3)	Year	Reported as	Ref.
18/08/1952	Frankton Arm	11				1952		3
26/11/1952	Frankton Arm	7.7				1952		3
5/01/1953	Frankton Arm	9.8				1953		3
6/02/1974	Frankton Arm	12.1	0.58			1974		**
15/12/1988	Frankton Arm	11	0.27	2*	30	1988	* <3	2
7/03/1989	Frankton Arm	12.5	0.47	2*	9#	1989	* <3 #<10	2
8/10/1989	Frankton Arm	14.6	0.42			1989		**
11/01/1990	Frankton Arm	11.17	0.29			1990		**
14/04/1990	Frankton Arm	11.77	0.74			1990		**
22/07/1990	Frankton Arm	16.85	0.4			1990		**
11/11/1992	Frankton Arm	12.79	0.25	3.75	63	1992		1
9/12/1992	Frankton Arm	12.38	0.7	3.75	65	1992		1
6/01/1993	Frankton Arm	12.32	0.3	1.5	66	1993		1
9/02/1993	Frankton Arm	10	0.5	4.25	100	1993		1
3/09/1993	Frankton Arm	14.93	0.6	3.5	58	1993		1
6/04/1993	Frankton Arm	14.2	0.3	6	73	1993		1
4/05/1993	Frankton Arm	13.47	0.5	3.33	38	1993		1
3/08/1993	Frankton Arm	16.15	0.5	3.75	75	1993		1
7/09/1993	Frankton Arm	15.2	0.55	3	71	1993		1
5/10/1993	Frankton Arm	17.27	0.5	4.75	53	1993		1
9/11/1993	Frankton Arm	13.9	0.11	1.75		1993		1
7/12/1993	Frankton Arm	14.82	0.2	4.5		1993		1
18/01/1994	Frankton Arm	4.65	0.55	8.75		1994		1
8/02/1994	Frankton Arm	3.5	0.35	4.67		1994		1
8/03/1994	Frankton Arm	4.45	0.8	3.33		1994		1
6/04/1994	Frankton Arm	6.35	0.4	3.25		1994		1
3/05/1994	Frankton Arm	8.5	0.6	7.75		1994		1
8/06/1994	Frankton Arm	7.5	0.7	2.5		1994		1
9/08/1994	Frankton Arm	8	0.39	22.75	78	1994		1
6/09/1994	Frankton Arm	6.97	0.27	13.25	75	1994		1
4/10/1994	Frankton Arm	7.83	0.26	1.5	70	1994		1
6/12/1994	Frankton Arm	6.2	0.36	1.75	64	1994		1
10/01/1995	Frankton Arm	5.6	0.25	3.5	84	1995		1
7/03/1995	Frankton Arm	12.15	0.24	6	65	1995		1
21/04/1995	Frankton Arm	13.8	0.49	6	55	1995		1
13/06/1995	Frankton Arm	10.59	0.34	12.25	115	1995		1
8/04/1994	Frankton Arm	6.5	0.75			1994		4
5/05/1994	Frankton Arm		1.01			1994		4
9/06/1994	Frankton Arm	8.5	2.02	3.81	45	1994		4
7/07/1994	Frankton Arm		0.35	1.43	38	1994		4
4/08/1994	Frankton Arm	6.75	0.6	1.85	62	1994		4

Date	Site	Secchi depth (m)	Chla (mg/m^3)	TP (mg/m^3)	TN (mg/m^3)	Year	Reported as	Ref.
8/09/1994	Frankton Arm	9.75	0.43	5.29	56	1994		4
7/10/1994	Frankton Arm	4.5	0.43	0.98	73	1994		4
4/11/1994	Frankton Arm		0.39	0.84	106	1994		4
1/12/1994	Frankton Arm	8.5	0.62	1.94	28	1994		4
15/01/1995	Frankton Arm		0.54	3.85	39	1995		4
6/02/1995	Frankton Arm	9	0.39	4.17	43	1995		4
5/03/1995	Frankton Arm		0.38	4.48	61	1995		4
12/04/1997	Frankton Arm	15.33	0.42			1997		5
24/06/1997	Frankton Arm	16	0.42		67	1997		5
2/09/1997	Frankton Arm	19.5	0.26	2.1	37	1997		5
10/11/1997	Frankton Arm	11	0.64	5.17	36	1997		5
3/02/1998	Frankton Arm	10.7	0.45	8.3	75	1998		5
29/04/1998	Frankton Arm	11	0.64	11.1	66	1998		5
18/08/1952	Open Water	10						8
4/02/1953	Open water	10.5						8
4/04/1953	Open water	8.5						8
23/06/1953	Open water	9.5						8
15/12/1988	Open water	11	0.31	2*	28		* <3	5
7/03/1989	Open water	15						5
12/04/1997	Open water	12.3	0.37					5
24/06/1997	Open water	16.5	0.4		32			5
2/09/1997	Open water		0.26	2.72	62			5
10/11/1997	Open water		0.58	3.67	110			5
3/02/1998	Open water	14.5	0.4	6.35	89			5
29/04/1998	Open water	11	0.63	12	55			5
15/09/1988	Queenstown Bay			5.1	36			2
15/12/1988	Queenstown Bay	7	0.4	2*	29		* <3	2
7/03/1989	Queenstown Bay	11	0.63	2*	9#		* <3 #<*10*	2
12/04/1997	Queenstown Bay	7.2	0.14					5
24/06/1997	Queenstown Bay	12.5	0.4		42			5
2/09/1997	Queenstown Bay	11.3	0.32	0.83	29			5
10/11/1997	Queenstown bay		0.74	5.52	58			5
3/02/1998	Queenstown Bay	11.2	0.42	6.8	82			5
29/04/1998	Queenstown Bay	8.5	0.92	11.2	63			5

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Lake Wakatipu: Sample results: Frankton Arm

Lake: Wakatipu Station: Frankton Arm

Date	depth	TP (mg/m^3)	TN (mg/m^3)	Chla (mg/m^3)	NO3 (mgN/m^3)	NH4 (mgN/m^3)	DRP (mgP/m^3)
11/05/2006	8	2.5	70	0.5	18	5	2.5
	23.4	6	60	0.5	18	5	2.5
13/06/2006	23.4	6	230	0.48	22	5	2.5
	8	5	290	0.48	23	5	2.5
11/07/2006	23.4	5	25	0.34	20	5	2.5
	8	5	90	0.34	20	5	2.5
14/08/2006	8	5	130	0.27	2.5	5	2.5
	23.4	5	190	0.27	2.5	5	7
11/09/2006	23.4	2.5	70	0.11	31	5	2.5
	8	2.5	160	0.11	33	10	2.5
16/10/2006	8	2.5	140	0.35	30	10	2.5
	23.4	2.5	80	0.35	29	10	56
13/11/2006	23.4	2.5	70	0.2	25	5	2.5
	8	2.5	130	0.2	26	5	2.5
06/12/2006	8	2.5	70	0.2	29	10	2.5
	23.4	5	130	0.2	29	5	2.5
14/01/2007	23.4	7	120	0.32	22	5	2.5
	8	11	280	0.32	25	10	2.5
13/02/2007	8	2.5	60	0.37	17	10	2.5
	23.4	2.5	80	0.37	17	5	2.5
16/03/2007	23.4	2.5	60	0.29	17	10	2.5
	8	2.5	130	0.29	17	5	2.5
11/04/2007	23.4	8	70	0.4	27	5	2.5
	8	7	70	0.03	18	5	2.5
02/05/2007	23.4	6	120	0.65	18	5	2.5
	8	2.5	80	0.65	18	5	2.5
20/06/2007	8	5	70	0.5	24	5	2.5
	23.4	5	60	0.5	25	5	2.5
19/09/2007	23.4	6	130	0.37	31	5	2.5
	8	2.5	120	0.37	33	5	2.5
18/10/2007	23.4	2.5	140	0.46	28	5	2.5
	8	2.5	70	0.46	28	5	2.5
12/11/2007	23.4	2.5	90	0.26	30	5	2.5
	8	2.5	120	0.26	29	5	2.5
04/12/2007	23.4	5	100	0.19	24	5	2.5
	8	2.5	70	0.19	28	5	2.5
16/01/2008	23.4	5	90	0.21	16	5	2.5
	8	6	90	0.21	23	5	2.5
11/02/2008	23.4	17	310	0.07	17	10	2.5
	8	2.5	190	0.07	21	10	2.5
10/03/2008	8	5	120	1.1	19	5	2.5
	23.4	6	100	1.1	19	5	2.5
14/04/2008	23.4	5	200	0.37	19	5	2.5
	8	5	100	0.37	20	10	2.5

Lake: Wakatipu Station: Frankton Arm

Date	depth from	TP (mgP/m^3)	TN (mg/m^3)	Chla (mg/m^3)	NO3 (mgN/m^3)	NH4 (mgN/m^3)	DRP (mgP/m^3)
19/05/2008	23.4	2.5	50	0.27	26	5	2.5
	8	2.5	80	0.27	20	5	2.5
19/06/2008	23.4	5	130	0.62	24	5	2.5
	8	5	90	0.56	19	5	2.5
14/07/2008	8	5	130	0.65	24	10	2.5
	23.4	6	100	0.64	24	10	2.5
12/08/2008	8	2.5	80	0.71	23	5	2.5
	23.4	2.5	70	0.76	23	5	2.5
15/09/2008	21.2	2.5	70	0.77	21	5	2.5
	7.1	2.5	100	0.2	27	10	2.5
21/10/2008	23.4	2.5	25	0.46	31	5	5
	8	2.5	140	0.19	30	5	2.5
19/11/2008	23	2.5	160	0.48	31	5	2.5
	7.7	2.5	100	0.26	29	5	2.5
17/12/2008	7.7	2.5	80	0.26	26	5	2.5
19/01/2009	23.5	7	80	0.48	19	5	5
	7.8	10	100	0.37	22	5	5
16/02/2009	7.6	6	150	0.38	20	5	2.5
	22.7	6	25	0.48	22	5	2.5
16/03/2009	22.5	2.5	80	0.6	18	5	2.5
	7.5	2.5	80	0.5	19	5	2.5
21/04/2009	22.8	6	100	0.42	22	10	5
	7.6	8	80	0.31	22	5	5

Lake Wakatipu: Secchi depth (m): Frankton Arm

Date	Secchi depth (m)	Date	Secchi depth (m)	Date	Secchi depth (m)	Date	Secchi depth (m)
11/05/2006	8.5	13/02/2007	10	16/01/2008	11	21/10/2008	15.8
13/06/2006	8.9	16/03/2007	9.2	11/02/2008	13	19/11/2008	14
11/07/2006	9	11/04/2007	13.2	10/03/2008	9.9	17/12/2008	14.2
14/08/2006	13.5	02/05/2007	14	14/04/2008	13	19/01/2009	12.9
11/09/2006	15.8	20/06/2007	12.7	19/05/2008	14.5	16/02/2009	11.3
16/10/2006	13.8	19/09/2007	12.8	19/06/2008	14.1	16/03/2009	14
13/11/2006	14.4	18/10/2007	12.5	14/07/2008	17	21/04/2009	15.1
06/12/2006	12.4	12/11/2007	11.5	12/08/2008	16.4		
14/01/2007	9	04/12/2007	14	15/09/2008	15.3		

Lake Wakatipu: Sample results: open water

Date	Depth	TP mg/m^3	TN mg/m^3	Chla mg/m^3	NO3 mg/m^3	NH4 mg/m^3	DRP mg/m^3
11/05/2006	150	7	25	0.27	22	5	2.5
	50	5	80	0.27	21	5	2.5
13/06/2006	150	2.5	200	0.36	26	10	2.5
	50	7	70	0.36	23	10	2.5
11/07/2006	150	5	70	0.28	41	5	5
	50	5	70	0.28	44	5	2.5
14/08/2006	50	23	210	0.3	32	50	7
	150	2.5	150	0.3	33	5	9
11/09/2006	150	2.5	90	0.16	38	5	2.5
	50	2.5	110	0.16	36	10	2.5
16/10/2006	150	2.5	80	0.33	32	10	2.5
	50	7	260	0.33	34	5	2.5
13/11/2006	150	2.5	90	0.49	35	5	2.5
	50	2.5	25	0.49	32	5	2.5
06/12/2006	150	2.5	130	0.49	37	5	2.5
	50	13	90	0.49	2.5	5	2.5
14/01/2007	50	7	70	0.28	31	5	2.5
	150	7	100	0.28	38	5	2.5
13/02/2007	50	2.5	60	0.44	24	5	2.5
	150	2.5	130	0.44	30	5	2.5
16/03/2007	150	2.5	70	0.2	38	5	2.5
	50	2.5	90	0.2	24	5	2.5
11/04/2007	150	10	140	0.5	40	5	2.5
	50	9	80	0.5	20	5	2.5
02/05/2007	150	50	220	0.36	38	5	2.5
	50	7	310	0.36	23	5	2.5
20/06/2007	150	5	60	0.49	41	5	2.5
	50	2.5	50	0.49	27	5	5
19/09/2007	150	5	120	0.46	39	5	2.5
	50	6	170	0.46	37	5	2.5
18/10/2007	150	5	130	0.42	33	5	2.5
	50	2.5	70	0.42	29	5	2.5
12/11/2007	50	5	140	0.55	33	5	2.5
	150	5	140	0.55	36	5	2.5
04/12/2007	50	6	180	0.68	34	5	2.5
	150	5	130	0.68	37	5	2.5
16/01/2008	50	7	110	0.36	29	5	2.5
	150	8	300	0.36	40	5	2.5
11/02/2008	150	6	390	0.34	40	5	2.5
	50	2.5	180	0.34	26	5	2.5
10/03/2008	50	5	160	0.27	32	5	2.5
	150	5	80	0.27	41	5	2.5
14/04/2008	50	5	170	0.29	27	10	2.5
	150	9	220	0.29	41	5	2.5
19/05/2008	50	2.5	70	0.25	29	5	2.5
	150	2.5	90	0.25	41	5	2.5

Lake: Wakatipu Station: Open water

Date	Depth	TP mg/m^3	TN mg/m^3	Chla mg/m^3	NO3 mg/m^3	NH4 mg/m^3	DRP mg/m^3
19/06/2008	150	2.5	100	0.13	50	5	2.5
	50	2.5	90	0.33	25	5	2.5
14/07/2008	150	7	25	0.1	41	10	2.5
	50	5	110	0.34	31	10	2.5
12/08/2008	150	5	150	0.27	34	5	2.5
	50	10	80	0.48	30	5	2.5
15/09/2008	50	2.5	80	0.36	32	5	2.5
	150	7	280	0.29	31	5	2.5
21/10/2008	150	2.5	160	0.34	33	5	2.5
	50	10	180	0.52	30	5	2.5
19/11/2008	50	2.5	110	0.51	33	5	2.5
	150	2.5	120	0.29	37	5	2.5
17/12/2008	150	60	190	0.27	39	5	2.5
	50	2.5	80	0.59	28	5	2.5
19/01/2009	150	10	100	0.14	39	5	5
	50	29	110	0.38	29	5	5
17/02/2009	150	5	200	0.21	44	5	2.5
	50	5	100	0.34	31	5	2.5
16/03/2009	50	2.5	140	0.24	41	5	2.5
	150	6	100	0.17	28	5	2.5
21/04/2009	157.6	5	110	0.15	44	5	5
	52.5	0	110	0.17	34	5	5

Lake Wakatipu: Secchi depth (m): Open water

Date	Secchi depth	Date	Secchi depth	Date	Secchi depth	Date	Secchi depth
11/05/2006	9.1	13/02/2007	10.8	16/01/2008	10.2	21/10/2008	15.2
13/06/2006	10.5	16/03/2007	8.2	11/02/2008	9.3	19/11/2008	14
11/07/2006	16	11/04/2007	14.4	10/03/2008	7.4	17/12/2008	15.6
14/08/2006	16.2	02/05/2007	11.8	14/04/2008	13.8	19/01/2009	11
11/09/2006	15.4	20/06/2007	13.5	19/05/2008	20	17/02/2009	14.3
16/10/2006	14.6	19/09/2007	13.2	19/06/2008	14.9	16/03/2009	15.3
13/11/2006	13.4	18/10/2007	13.1	14/07/2008	14.8		
06/12/2006	15.2	12/11/2007	10	12/08/2008	16.8		
14/01/2007	12	04/12/2007	12.6	15/09/2008	14		

Lake Wakatipu: Sample results: Queenstown Bay

Lake: Wakatipu Station: Queenstown Bay

Date	Depth	TP mg/m^3	TN mg/m^3	Chla mg/m^3	NO3 mg/m^3	NH4 mg/m^3	DRP mg/m^3
11/05/2006	4.2	7	80	0.43	19	5	2.5
	12.6	6	60	0.43	19	5	2.5
13/06/2006	4.2	2.5	80	0.44	24	10	2.5
	12.6	6	60	0.44	24	5	2.5
11/07/2006	4.2	5	80	0.32	29	5	2.5
	12.6	5	50	0.32	30	5	2.5
14/08/2006	4.2	5	160	0.41	25	10	5
	12.6	6	80	0.41	20	10	6
11/09/2006	4.2	9	170	0.18	31	5	2.5
	12.6	23	420	0.18	32	10	2.5
16/10/2006	4.2	6	350	0.41	28	10	2.5
	12.6	6	190	0.41	32	10	2.5
13/11/2006	12.6	2.5	25	0.24	27	5	2.5
	4.2	8	70	0.24	24	5	2.5
06/12/2006	4.2	2.5	70	0.27	28	5	2.5
	12.6	2.5	80	0.27	24	5	2.5
14/01/2007	4.2	7	130	0.24	20	5	2.5
	12.6	13	120	0.24	28	5	2.5
13/02/2007	4.2	2.5	80	0.44	18	5	2.5
	12.6	7	90	0.44	17	10	2.5
16/03/2007	12.6	2.5	90	0.13	19	5	2.5
	4.2	2.5	100	0.13	19	5	2.5
11/04/2007	4.2	8	60	0.44	17	5	2.5
	12.6	10	110	0.44	16	5	2.5
02/05/2007	4.2	8	220	0.79	17	5	2.5
	12.6	7	170	0.79	17	5	2.5
20/06/2007	4.2	5	25	0.06	26	5	2.5
	12.6	2.5	60	0.06	25	5	2.5
19/09/2007	12.6	5	110	0.44	29	5	2.5
	4.2	6	180	0.44	31	5	2.5
18/10/2007	12.6	2.5	90	0.7	25	5	2.5
	4.2	2.5	70	0.7	25	5	2.5
12/11/2007	4.2	7	390	0.14	28	5	2.5
	12.6	6	350	0.14	26	5	2.5
04/12/2007	4.2	5	150	0.37	26	5	2.5
	12.6	6	170	0.37	24	5	2.5
16/01/2008	12.6	5	100	0.16	20	5	2.5
	4.2	7	90	0.16	20	5	2.5
11/02/2008	4.2	5	150	0.2	20	10	2.5
	12.6	7	280	0.2	18	10	2.5
10/03/2008	4.2	6	80	0.48	19	5	2.5
	12.6	2.5	80	0.48	20	5	2.5
14/04/2008	4.2	10	280	0.87	15	5	2.5
	12.6	2.5	80	0.87	15	5	2.5
19/05/2008	4.2	2.5	50	0.44	26	5	2.5

Lake: Wakatipu Station: Queenstown Bay

Date	Depth	TP mg/m^3	TN mg/m^3	Chla mg/m^3	NO3 mg/m^3	NH4 mg/m^3	DRP mg/m^3
	12.6	2.5	70	0.44	27	5	2.5
19/06/2008	12.6	5	110	0.47	23	5	2.5
14/07/2008	4.2	6	160	0.59	28	10	2.5
	12.6	8	130	0.63	28	10	2.5
12/08/2008	4.2	2.5	140	0.9	21	5	2.5
	12.6	2.5	120	0.81	22	5	2.5
15/09/2008	4.2	8	150	0.86	23	20	5
	12.6	8	380	1.55	19	5	2.5
21/10/2008	4.2	2.5	25	0.15	27	5	2.5
	12.6	6	110	0.19	28	5	2.5
19/11/2008	12.6	2.5	110	0.46	27	5	2.5
	4.2	5	140	0.5	26	5	2.5
17/12/2008	12.6	5	90	0.16	23	5	2.5
	4.2	2.5	90	0.36	23	5	2.5
19/01/2009	12.6	14	80	0.56	17	5	7
	4.2	8	110	0.51	20	5	5
16/02/2009	4.2	17	110	0.49	21	5	2.5
	12.6	7	90	0.47	22	5	2.5
16/03/2009	4.2	2.5	80	0.54	18	5	2.5
	12.6	2.5	150	0.71	14	5	2.5
21/04/2009	11.8	5	50	0.47	21	5	6
	3.9	6	150	0.44	20	5	5

Lake Wakatipu: Secchi depth (m): Queenstown Bay

Date	Secchi depth	Date	Secchi depth	Date	Secchi depth	Date	Secchi depth
11/05/2006	9	16/03/2007	7	10/03/2008	6.5	19/01/2009	9
13/06/2006	7.5	11/04/2007	10.1	14/04/2008	10.8	16/02/2009	10.3
11/07/2006	8.8	02/05/2007	10.9	19/05/2008	14.8	16/03/2009	12.8
14/08/2006	8.6	20/06/2007	11.8	19/06/2008	10	21/04/2009	11.7
11/09/2006	15.8	19/09/2007	11.5	14/07/2008	10.7		
16/10/2006	9.3	18/10/2007	8.3	12/08/2008	12.5		
13/11/2006	10.6	12/11/2007	10.8	15/09/2008	12		
06/12/2006	13.9	04/12/2007	14.5	21/10/2008	11.8		
14/01/2007	9.3	16/01/2008	8	19/11/2008	11		
13/02/2007	10	11/02/2008	10	17/12/2008	12.1		

Lake Wanaka: Sample results: Dublin Bay

Lake: Wanaka Station: Dublin Bay

Date	Depth	TP mg/m^3	TN mg/m^3	Chla mg/m^3	NO3 mg/m^3	NH4 mg/m^3	DRP mg/m^3	pH
12/05/2006	7.5	6	100	0.49	22	10	2.5	8.06
	23.5	5	80	0.49	23	5	2.5	8.06
14/06/2006	23.5	6	90	0.23	31	10	2.5	7.79
	7.5	47	200	0.23	35	20	5	7.79
12/07/2006	23.5	6	110	0.3	36	5	2.5	7.74
	7.5	7	80	0.3	41	5	2.5	7.74
15/08/2006	23.5	6	120	0.24	2.5	10	2.5	7.92
	7.5	2.5	60	0.24	35	5	2.5	7.92
12/09/2006	23.5	2.5	100	0.2	36	5	2.5	7.99
	7.5	2.5	90	0.2	40	10	2.5	7.99
17/10/2006	23.5	2.5	80	0.19	41	5	2.5	8.31
	7.5	2.5	130	0.19	38	20	7	8.31
14/11/2006	23.5	7	120	0.18	37	5	2.5	8.4
	7.5	5	100	0.18	36	5	2.5	8.4
07/12/2006	23.5	2.5	110	0.21	35	5	2.5	8.5
	7.5	6	240	0.21	37	5	2.5	8.5
15/01/2007	23.5	2.5	120	0.18	30	10	2.5	7.99
	7.5	11	110	0.18	29	5	2.5	7.99
12/02/2007	23.5	5	100	0.38	32	5	2.5	8.26
	7.5	5	80	0.38	22	10	5	8.26
15/03/2007	23.5	2.5	60	0.47	25	5	2.5	8.33
	7.5	2.5	120	0.47	17	5	2.5	8.33
12/04/2007	23.5	11	180	0.42	20	5	2.5	8.35
	7.5	9	60	0.42	18	5	2.5	8.35
03/05/2007	7.5	2.5	80	0.61	19	5	2.5	8.26
	23.5	2.5	130	0.61	18	5	2.5	8.26
21/06/2007	7.5	2.5	70	0.6	34	5	2.5	8.27
	23.5	2.5	90	0.6	31	5	2.5	8.27
18/09/2007	7.5	5	130	0.24	39	5	2.5	7.79
	23.5	6	120	0.24	37	5	2.5	7.79
17/10/2007	23.5	2.5	80	0.16	34	5	2.5	7.79
	7.5	2.5	140	0.16	35	5	5	7.79
13/11/2007	23.5	7	300	0.29	36	5	2.5	8
	7.5	7	210	0.29	36	5	7	8
05/12/2007	23.5	2.5	120	0.27	32	5	2.5	8.17
	7.5	5	140	0.27	27	5	2.5	8.17
17/01/2008	7.5	7	180	0.58	20	5	2.5	8.35
	23.5	8	320	0.58	22	5	2.5	8.35
11/02/2008	23.5	8	250	0.93	19	10	2.5	8.55
	7.5	8	220	0.93	12	10	2.5	8.55
11/03/2008	23.5	6	150	0.86	15	5	2.5	8.42
	7.5	5	180	0.86	15	5	2.5	8.42
15/04/2008	23.5	9	270	0.89	16	5	2.5	8.57
15/04/2008	7.5	9	260	0.93	9	5	2.5	8.57
20/05/2008	23.5	2.5	120	0.39	28	5	2.5	8.59

Lake: Wanaka Station: Dublin Bay

Date	Depth	TP mg/m³	TN mg/m³	Chla mg/m³	NO3 mg/m³	NH4 mg/m³	DRP mg/m³	pH
	7.5	2.5	80	0.39	30	5	2.5	8.59
18/06/2008	7.5	2.5	120	0.55	24	5	2.5	8.64
	23.5	2.5	150	0.55	24	5	2.5	8.62
15/07/2008	7.5	19	170	0.72	31	10	2.5	9.64
	23.5	5	100	0.64	31	10	2.5	9.64
13/08/2008	7.5	2.5	190	0.55	31	5	2.5	7.42
	23.5	2.5	290	0.43	29	5	2.5	7.45
16/09/2008	23.5	2.5	100	0.59	33	5	2.5	7.76
	7.5	2.5	80	0.46	33	5	2.5	7.77
22/10/2008	23.5	15	280	1.02	26	5	2.5	7.95
	7.5	11	110	0.61	26	5	2.5	7.99
20/11/2008	23.5	2.5	120	0.59	33	5	2.5	7.53
	7.5	2.5	90	0.3	32	5	2.5	7.55
18/12/2008	7.5	2.5	110	0.33	28	5	2.5	7.69
	23.5	6	120	0.54	32	5	2.5	7.59
20/01/2009	23.5	7	160	0.8	23	5	2.5	7.44
	7.5	9	240	0.66	22	5	2.5	7.51
17/02/2009	7.5	5	110	0.76	19	5	2.5	7.16
	23.5	2.5	80	0.86	25	5	2.5	7.12
17/03/2009	7.5	2.5	90	0.61	12	10	2.5	7.1
	23.5	2.5	140	0.89	14	5	2.5	7.09
22/04/2009	24.2	2.5	90	0.55	26	5	2.5	8.07
	8	2.5	150	0.53	21	5	5	8.15

Lake Wanaka: Secchi depth (m): Dublin Bay

Date	Secchi depth	Date	Secchi depth	Date	Secchi depth
12/05/2006	11.8	15/03/2007	9.3	15/04/2008	13.5
14/06/2006	10.9	12/04/2007	11.6	20/05/2008	13.7
12/07/2006	13.5	03/05/2007	12	18/06/2008	19.5
15/08/2006	20.5	21/06/2007	15.4	15/07/2008	17.5
12/09/2006	18	18/09/2007	16.9	13/08/2008	21.6
17/10/2006	13.2	17/10/2007	12.8	16/09/2008	11
12/11/2006	10	13/11/2007	11	22/10/2008	13.5
14/11/2006	14	05/12/2007	12.2	20/11/2008	12
07/12/2006	8.2	17/01/2008	8	18/12/2008	8.1
15/01/2007	11.9	11/02/2008	10.7	20/01/2009	8.3
12/02/2007	10.3	11/03/2008	10	17/02/2009	12.1
				17/03/2009	15.4
				22/04/2009	9.8

Lake Wanaka: Sample results: Roys Bay

Lake: Wanaka Station: Roys Bay

Date	Depth	TP mg/m^3	TN mg/m^3	Chla mg/m^3	NO3 mg/m^3	NH4 mg/m^3	DRP mg/m^3	pH
12/05/2006	17.5	5	100	0.21	28	10	2.5	8
	6.2	7	90	0.21	27	5	2.5	8
14/06/2006	6.2	8	60	0.14	31	10	2.5	7.83
	17.5	8	80	0.14	36	10	2.5	7.83
12/07/2006	6.2	8	100	0.4	42	5	2.5	7.65
	17.5	7	90	0.4	48	5	2.5	7.65
15/08/2006	17.5	2.5	110	0.2	34	5	5	7.93
	6.2	2.5	90	0.2	35	5	2.5	7.93
12/09/2006	6.2	2.5	80	0.11	45	10	2.5	8.06
	17.5	5	70	0.11	43	5	2.5	8.06
17/10/2006	6.2	2.5	90	0.17	40	10	2.5	8.31
	17.5	2.5	110	0.17	39	5	2.5	8.31
14/11/2006	6.2	6	190	0.3	31	5	2.5	8.44
	17.5	5	140	0.3	35	5	2.5	8.44
07/12/2006	17.5	2.5	100	0.14	35	5	2.5	8.53
	6.2	2.5	150	0.14	37	5	2.5	8.53
15/01/2007	17.5	5	80	0.18	33	10	2.5	8.02
	6.2	20	60	0.18	34	10	2.5	8.02
12/02/2007	6.2	5	80	0.38	22	10	2.5	8.31
	17.5	2.5	90	0.38	26	10	2.5	8.31
15/03/2007	6.2	2.5	80	0.22	17	5	2.5	8.35
	17.5	9	90	0.22	21	5	2.5	8.35
12/04/2007	17.5	9	210	0.5	21	5	2.5	8.35
	6.2	10	180	0.5	26	10	2.5	8.35
03/05/2007	6.2	2.5	220	0.98	30	5	2.5	8.19
	17.5	2.5	60	0.98	28	5	2.5	8.19
21/06/2007	6.2	2.5	80	0.62	34	5	2.5	8.27
	17.5	2.5	160	0.62	33	5	2.5	8.27
18/09/2007	6.2	2.5	140	0.13	43	5	2.5	7.85
	17.5	2.5	100	0.13	41	5	2.5	7.85
17/10/2007	6.2	8	210	0.14	34	5	2.5	7.85
	17.5	2.5	70	0.14	34	5	2.5	7.85
13/11/2007	17.5	2.5	120	0.11	37	5	2.5	8.11
	6.2	5	200	0.11	36	5	2.5	8.11
06/12/2007	6.2	8	400	0.23	30	5	2.5	8.24
	17.5	2.5	250	0.23	31	5	2.5	8.24
17/01/2008	6.2	7	220	0.63	23	5	2.5	8.37
	17.5	6	150	0.63	24	5	2.5	8.37
11/02/2008	6.2	5	130	0.86	14	10	2.5	8.54
	17.5	6	120	0.86	19	5	2.5	8.54
11/03/2008	6.2	8	260	0.53	12	5	2.5	8.47
	17.5	5	200	0.53	12	5	2.5	8.47
15/04/2008	17.5	7	120	0.61	22	5	2.5	8.56
	6.2	6	160	0.61	16	5	2.5	8.56
20/05/2008	6.2	2.5	110	0.11	27	5	2.5	8.69

Lake: Wanaka Station: Roys Bay

Date	Depth	TP mg/m^3	TN mg/m^3	Chla mg/m^3	NO3 mg/m^3	NH4 mg/m^3	DRP mg/m^3	pH
	17.5	2.5	100	0.11	22	5	2.5	8.69
18/06/2008	6.2	6	230	0.75	24	5	2.5	8.66
	17.5	6	180	0.81	26	5	2.5	8.64
15/07/2008	6.2	7	220	0.7	29	10	2.5	9.64
	17.5	10	270	0.73	32	10	2.5	9.64
13/08/2008	6.2	10	100	0.41	30	5	2.5	7.47
	17.5	2.5	80	0.43	30	5	2.5	7.46
16/09/2008	6.2	13	190	0.34	33	5	7	7.87
	17.5	5	120	0.58	32	5	2.5	7.85
22/10/2008	17.5	9	130	0.44	28	5	2.5	7.96
	6.2	8	90	0.25	28	5	2.5	8.04
20/11/2008	17.5	2.5	90	0.61	35	5	2.5	7.53
	6.2	2.5	130	0.3	34	5	2.5	7.62
18/12/2008	6.2	2.5	130	0.17	27	5	2.5	7.78
	17.5	5	320	0.86	25	5	2.5	7.78
20/01/2009	17.5	10	130	0.88	24	5	2.5	7.66
	6.2	10	200	0.61	21	5	5	7.71
17/02/2009	17.5	5	60	0.94	23	5	2.5	7.17
	6.2	6	80	0.55	22	5	2.5	7.21
17/03/2009	6.2	2.5	110	0.36	14	5	2.5	7.09
	17.5	2.5	120	0.96	14	5	2.5	7.11
22/04/2009	19.7	5	190	0.85	22	5	2.5	8.16
	6.5	6	170	0.49	22	10	7	8.21

Lake Wanaka: Secchi depth (m): Roys Bay

Date	Secchi depth	Date	Secchi depth	Date	Secchi depth
12/05/2006	11	03/05/2007	12.3	15/07/2008	15.3
14/06/2006	10.7	21/06/2007	13.4	13/08/2008	21.9
12/07/2006	12.5	18/09/2007	12.7	16/09/2008	11.5
15/08/2006	10.7	17/10/2007	13.2	22/10/2008	12.5
12/09/2006	15.3	13/11/2007	9.3	20/11/2008	12.5
17/10/2006	12.8	06/12/2007	11	18/12/2008	10.6
14/11/2006	12.6	17/01/2008	8.5	20/01/2009	8.6
07/12/2006	6.6	11/02/2008	12.3	17/02/2009	11.8
15/01/2007	11.6	11/03/2008	10	17/03/2009	15.7
12/02/2007	10	15/04/2008	12.4	22/04/2009	10.3
15/03/2007	9	20/05/2008	16		
12/04/2007	10.4	18/06/2008	16.4		

Lake Wanaka: Sample results: Open water

Lake: Wanaka Station: Open Water

Date	Depth	TP mg/m^3	TN mg/m^3	Chla mg/m^3	NO3 mg/m^3	NH4 mg/m^3	DRP mg/m^3	pH
12/05/2006	50	6	80	0.4	28	5	2.5	8.15
	150	5	100	0.4	38	10	2.5	8.15
14/06/2006	150	7	70	0.48	51	10	2.5	7.6
	50	6	190	0.48	34	20	2.5	7.6
12/07/2006	150	7	240	0.37	39	5	2.5	7.78
	50	7	170	0.37	37	10	2.5	7.78
15/08/2006	50	2.5	180	0.21	35	5	2.5	7.92
	150	2.5	170	0.21	35	5	2.5	7.92
12/09/2006	150	2.5	70	0.24	43	5	2.5	7.98
	50	5	120	0.24	43	10	2.5	7.98
17/10/2006	150	2.5	100	0.4	45	10	6	8.16
	50	2.5	130	0.4	44	10	5	8.16
14/11/2006	150	2.5	170	0.2	44	10	2.5	8.33
	50	7	120	0.2	37	5	2.5	8.33
07/12/2006	50	2.5	120	0.8	41	10	2.5	8.38
	150	2.5	250	0.8	44	10	2.5	8.38
15/01/2007	50	6	140	0.2	41	20	2.5	7.8
	150	5	60	0.2	47	10	2.5	7.8
12/02/2007	150	2.5	70	0.61	40	5	2.5	7.98
	50	7	160	0.61	33	5	2.5	7.98
15/03/2007	150	2.5	130	0.9	48	5	2.5	8.11
	50	2.5	90	0.9	32	10	5	8.11
12/04/2007	50	10	220	0.79	32	5	2.5	8.21
	150	9	110	0.79	50	5	2.5	8.21
03/05/2007	150	2.5	80	0.08	48	5	2.5	8.1
	50	2.5	70	0.08	29	5	2.5	8.1
21/06/2007	150	2.5	90	0.5	49	5	2.5	8.31
	50	2.5	190	0.5	36	5	2.5	8.31
18/09/2007	150	7	230	0.93	43	5	2.5	7.38
	50	6	80	0.93	43	5	2.5	7.38
17/10/2007	150	2.5	110	0.28	38	5	2.5	7.87
	50	5	210	0.28	36	5	2.5	7.87
13/11/2007	50	5	280	0.38	38	5	2.5	7.97
	150	5	80	0.38	45	5	2.5	7.97
06/12/2007	150	2.5	100	0.43	45	5	2.5	8.11
	50	2.5	240	0.43	36	5	2.5	8.11
17/01/2008	150	8	240	0.65	49	5	2.5	8.24
	50	10	320	0.65	28	5	2.5	8.24
11/02/2008	150	5	140	0.42	48	5	2.5	8.16
	50	9	340	0.42	37	5	2.5	8.16
11/03/2008	150	9	230	0.92	51	5	2.5	8.41
	50	8	100	0.92	16	5	2.5	8.41
15/04/2008	50	6	110	0.26	31	5	2.5	8.27
	150	5	120	0.26	49	5	2.5	8.27
20/05/2008	150	2.5	130	0.39	56	5	2.5	8.28

Lake: Wanaka Station: Open Water

Date	Depth	TP mg/m^3	TN mg/m^3	Chla mg/m^3	NO3 mg/m^3	NH4 mg/m^3	DRP mg/m^3	pH
	50	2.5	100	0.39	23	5	2.5	8.28
18/06/2008	150	6	160	0.23	49	5	2.5	8.34
	50	10	210	0.74	31	5	2.5	8.6
15/07/2008	150	7	130	0.53	35	10	2.5	9.51
	50	2.5	110	0.73	34	10	2.5	9.65
13/08/2008	150	2.5	90	0.52	32	5	2.5	7.33
	50	2.5	130	0.58	35	5	2.5	7.32
16/09/2008	150	2.5	80	0.64	34	5	2.5	7.66
	50	2.5	100	0.63	34	10	2.5	7.65
22/10/2008	150	14	110	0.56	37	5	2.5	7.72
	50	20	160	0.64	29	5	2.5	7.88
20/11/2008	150	2.5	150	0.37	44	5	2.5	7.29
	50	2.5	180	0.53	37	5	2.5	7.45
18/12/2008	50	6	220	0.28	37	5	2.5	7.46
	150	2.5	120	0.21	44	5	2.5	7.36
20/01/2009	150	8	150	0.15	51	5	5	7.1
	50	27	140	0.57	33	5	2.5	7.35
17/02/2009	150	5	120	0.15	52	5	2.5	6.69
	50	2.5	140	0.4	36	5	2.5	6.94
17/03/2009	150	2.5	100	0.16	52	5	2.5	6.55
	50	2.5	100	0.64	33	5	2.5	6.82
22/04/2009	150	5	150	0.24	54	5	2.5	7.7
	50	5	130	0.47	31	5	2.5	7.95

Lake Wanaka: Secchi depth (m): Open water

Date	Secchi depth	Date	Secchi depth	Date	Secchi depth
12/05/2006	11.8	03/05/2007	15.2	15/07/2008	17.5
14/06/2006	11.8	21/06/2007	15.7	13/08/2008	19.2
12/07/2006	11	18/09/2007	17.5	16/09/2008	14.6
15/08/2006	21.4	17/10/2007	12.7	22/10/2008	13
12/09/2006	18.3	13/11/2007	10.1	20/11/2008	14
17/10/2006	11.9	06/12/2007	13.8	18/12/2008	9.4
14/11/2006	13.6	17/01/2008	9.5	20/01/2009	9
07/12/2006	8.3	11/02/2008	10	17/02/2009	10.9
15/01/2007	12.8	11/03/2008	10	17/03/2009	16.4
12/02/2007	9.3	15/04/2008	12	22/04/2009	10.6
15/03/2007	9	20/05/2008	12.3		
12/04/2007	9.6	18/06/2008	17.8		