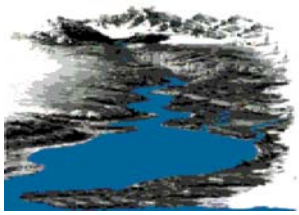


LAKES CONSULTING

Protocol for Monitoring Trophic Levels of New Zealand Lakes and Reservoirs

Noel Burns of Lakes Consulting
and
Graham Bryers,
Eddie Bowman of NIWA, Hamilton

prepared for the

Ministry for the Environment

Lakes Consulting
Client Report: 99/2
March 2000

Lakes Consulting
PO Box 161
Pauanui 2850, New Zealand

Table of Contents

Acknowledgements

We would like to acknowledge the contributions of the Foundation for Research, Science and Technology, the National Institute of Water and Atmospheric Research (NIWA) and the Ministry for the Environment towards the completion of this work. We are grateful to Environment Waikato and Taranaki Regional Council for use of some of their data, and to John McIntosh and Joanne Deely of Environment B·O·P and Kerry Costley of NIWA Hamilton for their help.

Abbreviations

Chla	Chlorophyll *a*
DO	Dissolved oxygen
DRP	Dissolved reactive phosphorus
EC	Electrical conductivity
HVOD	Hypolimnetic volumetric oxygen depletion rate
ISS	Inorganic suspended solids
NH_4	Ammonium
NO_3	Nitrate
NZLMP	New Zealand lakes monitoring programme
Opacity	Inverse of Secchi depth values (1/SD)
PAC	Percent annual change
OSS	Organic suspended solids
Pdiff	Total phosphorus concentrations minus dissolved reactive phosphorus concentrations
SD	Secchi depth
TLI	Trophic level index
TLx	Trophic level for a variable
TN	Total nitrogen
TON	Total organic nitrogen
TP	Total phosphorus
T/DO profiles	Temperature and dissolved oxygen depth profiles
TSS	Total suspended solids
Turb	Turbidity

Executive summary

The New Zealand Lakes Monitoring Programme was set up to provide a useful database on the trophic condition of some of New Zealand's more important lakes and to use this database to develop a sensitive, cost-effective Lakes Monitoring Protocol for detecting small changes in the trophic state of lakes. Such data are essential to initiating timely remedial action in the event of deterioration of water quality.

The trophic state of a lake is most simply defined as the life-supporting capacity per unit volume of a lake. Six commonly measured variables are widely accepted as good indicators of the trophic level of a lake: chlorophyll *a* (Chla), Secchi depth (SD), total phosphorus (TP), total nitrogen (TN), hypolimnetic volumetric oxygen depletion rate (HVOD) and phytoplankton species and biomass. These variables yield considerable relevant information on trophic level relative to the effort required for their measurement.

The system of lake monitoring and data analysis presented in this manual demonstrates how decisions on the probability of trophic level change can be made on the basis of numerical results, and assigns a numerical value for the trophic level of a lake and shows how a change in this value can be quantified. A decision on the probable change in a lake is made using percent annual change (PAC) values, while the trophic condition of a lake and the magnitude of change in this condition is assessed using trophic level index (TLI) values.

The protocol explains both the theory and practice necessary to establish a TLI value for a lake. Data sampling and data analysis methods are tailored to fit New Zealand conditions. Case studies are presented illustrating trophic change in New Zealand lakes and a more general reporting of ecological condition.

The manual provides advice on good practice in sampling technique on the lake, sample handling, laboratory analysis, compiling the data into a basic data file and calculating the monitoring results. Considerable emphasis is placed on identification of the different thermal layers in a lake and on averaging values only from samples within the same layer.

After baseline monitoring has been carried out on a lake, it is possible to optimise the sampling strategies to reduce unnecessary data collection. A costing study illustrates the choices that may be made to obtain the best possible monitoring data for a given budget.

Chapter 1. Concepts used in formulating the Lakes Monitoring Protocol

1.1 Introduction to lakes monitoring

New Zealand's lakes and reservoirs are rarely static in their water quality or ecological condition. Research initiatives such as the New Zealand Lakes Monitoring Programme (NZLMP) have been established to collect and develop relevant, useful data for determining the status of lake water quality and to detect changes in quality over time. Such data are essential to initiating timely remedial action in the event of deterioration of water quality.

Trophic levels of lakes are critical indicators of water quality. They provide a measure of the nutrient status of a body of water. This protocol document on lake monitoring aims to specify a cost-effective method for determining the trophic levels of lakes, and changes in these levels with time. Chapter 1 outlines the concepts used in lake monitoring and illustrates them with results obtained from their use in the NZLMP. Some of the ideas and results shown in this chapter will be presented again in greater detail in subsequent sections.

1.2 Objectives of monitoring

The large sums of money necessary to carry out an effective water-quality monitoring mean that the objectives for the project need to be clearly specified. Another reason for having clear objectives is that the structure of a monitoring programme largely depends on the reasons for the monitoring, as will be shown later. And, if a desired outcome from the monitoring is clearly stated, then the data collected can be inspected to see if they are meeting the purpose of the monitoring. In the past, monitoring has sometimes been done without clear objectives – merely for the sake of collecting data. This is usually a futile and wasteful exercise because the collected data are seldom checked and poor data collection procedures are not identified, which can lead to useless and relatively expensive files of data. Also, taking data that have been collected without a clear purpose and attempting to use them for some subsequently identified purpose may fail because the data are usually found to have some important element missing. If objectives are specified in the planning phase of a monitoring programme, several objectives can often be accommodated without incurring excessive extra expense compared with the cost of a basic monitoring programme.

As an example of stating objectives, those identified for the NZLMP were:

- to provide a good database on the trophic condition, in the 1990s, of some of New Zealand's more important lakes
- to use this database to develop a sensitive, cost-effective Lakes Monitoring Protocol for detecting small changes in the trophic state of lakes.

During the NZLMP, 23 lakes were monitored for periods from two to four years and produced data of good quality that have enabled formulation of a monitoring protocol for lakes. The trophic condition of these lakes has been well characterised. Results from analysis of this data will be used throughout this manual to illustrate various procedures (Burns and Rutherford, 1998).

The protocol specifies methods for determining the trophic levels of lakes and their changes over time. This is not the same as determining the water quality of a lake, which would also require observation of the levels of bacterial counts and toxic materials, in addition to the variables associated with trophic condition. Neither is determination of trophic state the same as determining ecological condition, which would require assessment of species richness and diversity in the littoral, benthic and offshore zones of a lake (Ward and Pyle, 1997). Monitoring of these different elements can be combined, but

each additional objective increases the cost of the exercise and should be balanced against the benefits to be obtained from its inclusion before a final decision on the structure of a monitoring programme.

1.3 Key variables defining trophic level

The concept of the trophic state of a lake incorporates several aspects, but may be simply defined as the *life-supporting capacity per unit volume of a lake*. Many aspects of a lake – physical (such as whether a lake is stratified by temperature into upper epilimnion, middle thermocline and lower hypolimnion layers), chemical, geological and biological – affect or control the trophic level of a lake, as described in the *Lake Manager's Handbook* (Vant, 1987). There are six commonly measured variables which are widely accepted as good indicators of the trophic state or level of a lake: chlorophyll *a* (Chla), Secchi depth (SD), total phosphorus (TP), total nitrogen (TN), hypolimnetic volumetric oxygen depletion rate (HVOD) and phytoplankton species and biomass. These variables – generally used because they yield considerable relevant information on trophic level relative to the effort required for their measurement – will be described hereafter in this text as the key variables. The primary productivity of lake waters, for example, has been used as a trophic level indicator but, because of the time and labour involved in carrying out these measurements, it is not recommended as a key trophic level variable in this protocol.

The evaluation of lake trophic level can use different variables. In the past, White (1977) and Chapra and Dobson (1981) described trophic state by comparing values given by epilimnetic data, such as Chla and SD, with the hypolimnetic concentration of dissolved oxygen (DO) at the end of the stratified season. Comparison of epilimnetic variables with hypolimnetic ones has not always worked well in the past because the effect of epilimnetic conditions on hypolimnetic DO can be variable, as it depends on the thickness of the hypolimnion and this differs from lake to lake. For example, Lake Rotokakahi has average epilimnetic Chla concentrations of 2.3 mg m^{-3} and could almost be classed as an oligotrophic lake, yet it undergoes almost two months per year of hypolimnetic anoxia, a condition often associated with eutrophic lakes.

Therefore, in this manual the description of the trophic level of a stratified lake is done with *values* from its epilimnion in a fully mixed isothermal condition only; it does not include any hypolimnetic values. This reduces the possibility of inconsistent signals from variables from different water masses. When change of trophic level with time is considered, however, *rates of change* from both epilimnetic and hypolimnetic variables can be considered; that is, the annual change in epilimnetic Chla concentration can be compared with annual change in the hypolimnetic HVOD rate.

1.4 Data analysis concepts

Determining whether a lake has undergone a small degree of deterioration enables remedial work to be started before the lake has undergone extensive degradation. Large-scale change in the trophic condition of a lake is easy to detect because obvious, consistent changes usually occur in all six key variables – the observed changes all indicate either degradation or improvement. However, when there is no real change in trophic level, these variables can vary, usually independently of each other. For example, if phytoplankton growth in a lake is limited by phosphorus availability, TN can increase without a concomitant increase in phytoplankton. Phytoplankton species may change from those with a relatively low Chla content to others containing a lot of Chla per unit biomass, thus increasing the Chla content of the lake when little else has changed. Floods can introduce a lot of organic and/or inorganic matter from the catchment into a lake; the organic matter can affect the oxygen depletion rate and the inorganic matter will alter the Secchi depth, even though little else in the lake will have changed.

However, a small but definite change in trophic state will cause consistent changes in all six of the key parameters, although these changes may not all be observable because of short-term variability or difficulty in detecting a small degree of change in parameters. To increase the sensitivity to detecting changes of trophic state, all six key variables have been monitored and a method developed for combining that information into an index of change in trophic level.

In the past, changes in lake trophic condition have usually been described in qualitative terms. The aim of the system of lake monitoring and data analysis presented in this manual is to (a) demonstrate how decisions on the probability of trophic level change can be made on the basis of numerical results, and (b) assign a numerical value for the trophic level of a lake and show how a change in this value can be quantified. A decision on the probable change in a lake is made using percent annual change (PAC) values, while the trophic condition of a lake and the magnitude of change in this condition is assessed using trophic level index (TLI) values.

The changes in Chla, SD and nutrient concentrations that a stratified lake undergoes with change of season are usually large and obvious; these seasonal changes can often mask small-scale change in these variables when the trophic level of a lake alters. Thus the data on the key variables need to be 'deseasonalised' to remove seasonal variability, where possible, before time trend analysis of this data is undertaken. Also, since shallow, unstratified lakes are often very perturbed by weather events (such as resuspension of bottom materials by strong winds), total and inorganic suspended materials are measured in shallow lakes to gauge the magnitude of this effect.

1.5 Types of monitoring

Lakes can be classified on the basis of their geological origin, their biology or their physical behaviour. Planning for trophic-state monitoring requires a physical classification of lakes because thermal stratification – or lack of it – is the dominant factor controlling Chla, nutrient and dissolved oxygen concentrations during an annual cycle. Wind-induced turbulence often controls the macrophytes in shallow lakes, and depth usually controls much of the biological functioning of large lakes.

There are two major types of lake requiring different sampling strategies:

- shallow, unstratified lakes
- deeper, stratified lakes.

These two types of lake break down into five finer categories that result in some modification of the basic sampling plans. These are:

1 unstratified lakes – phytoplankton dominated

2 unstratified lakes – macrophyte dominated

3 intermittently stratified lakes

4 stratified, smaller lakes – less than about 100 km^2 in area and 100 m maximum depth

5 stratified, large lakes – greater than about 100 km^2 in area and 100 m maximum depth.

Two sampling patterns were used in the NZLMP and are recommended here:

- Unstratified conditions in lakes are sampled at one-quarter and three-quarters of the depth at the sampling station.
- Stratified conditions are sampled from four equally spaced depths in the epilimnion, and the samples are pooled to create a single sample. A single hypolimnion sample is obtained from the middle of the hypolimnion.

These guidelines apply to the first four lake categories above, with both intermittently and normally stratified lakes being sampled according to absence or presence of stratification at their time of sampling. Pooling of samples is done to obtain samples representative of their layer, while minimising analytical costs. No sampling patterns are recommended for the stratified, large lakes. These lakes are very expensive to monitor and require individually designed monitoring programmes.

There are two principal types of monitoring:

- baseline trophic level monitoring

- routine monitoring.

The choice of method is made at the time of selecting the objectives of the monitoring. Baseline trophic level monitoring should be carried out if a good and trustworthy data set is not available for a lake. The baseline trophic level data set should establish a firm TLI value for a lake which then can be compared to other TLI values, determined at a later date, to check whether the trophic level of the lake has changed or been sustained. When baseline trophic data are being collected, enough data should be collected to enable the limnological character of the lake to be established. Soluble nutrient, pH and conductivity data should be collected from both the epilimnion and hypolimnion, and shallow lakes should undergo macrophyte surveys.

The number of sampling stations also requires consideration. The NZLMP results showed that spatial correlation existed between the two stations sited on each of Lakes Hayes and Okareka, so that, strictly speaking, only one sampling station was required on each of these lakes. However, this became clear only after an analysis of the information that had been collected. An outline of Lake Hayes (Figure 5.1) shows that it is 3.1 km long with an area of 2.03 km^2; Lake Okareka (Figure 6.10) is 2.8 km long with an area of 3.46 km^2. When baseline monitoring is put in place, there should be at least two sampling stations situated a significant distance apart on a lake so that a spatial correlation test can be carried out on the data. A second sampling station is not usually an expensive addition because the cost of analysing a few extra samples is usually small compared with the cost of travelling to a lake and setting a boat on it. Baseline monitoring should be carried out for a minimum of two years at monthly intervals. In August almost all New Zealand lakes are isothermal, so the limnological year is taken from 1 September to 31 August.

When the nature of a lake is sufficiently well documented, then routine monitoring strategies can be considered so as to conserve monitoring funds. These monitoring strategies are designed by analysing the data collected during the baseline monitoring. Usually, the number of stations sampled can be decreased to only one. Also, sampling frequencies may be able to be diminished and optimised by analysing the previously collected monthly sampling data.

Monitoring of specific sites for special reasons can also be considered. For example, nearshore sites can be located in large lakes close to cities to find out whether there are inputs from the cities, as concentrations are likely to be higher close to the source of inputs. Samples from these sites are more likely to detect inputs than samples from mid-lake sites, where concentration changes will take a long time to occur. Large-lake sampling strategies, nevertheless, should also incorporate some mid-lake stations for provision of baseline trophic level data.

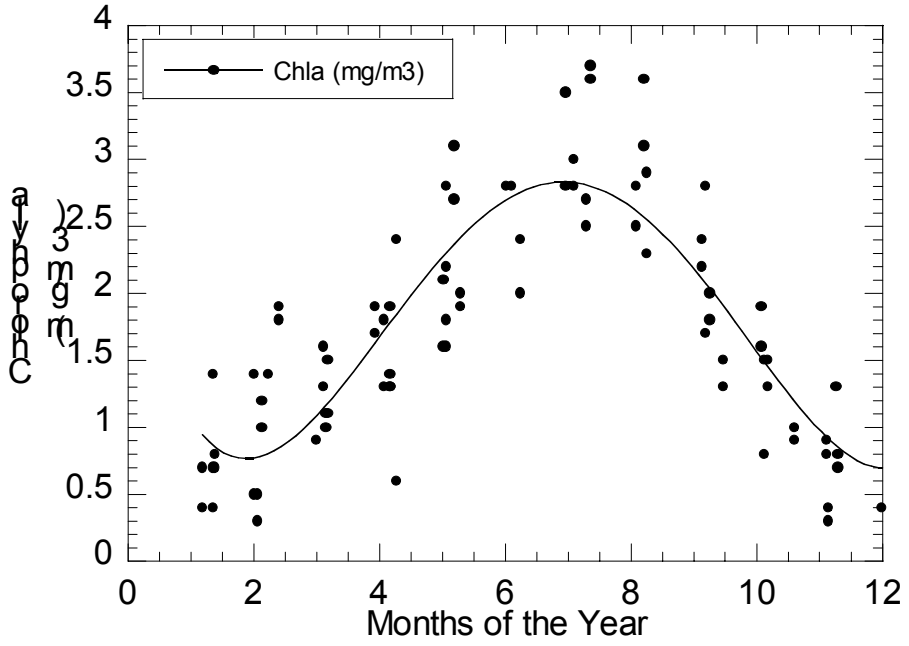
If trophic level monitoring reveals that a lake is undergoing deterioration, it may be necessary to implement diagnostic monitoring of specific sites, or diagnostic investigations of a specialised type to find the cause of the increasing eutrophication so that remedial measures can be put in place.

1.6 Trend detection using percent annual change values

The prime objective of monitoring is usually to detect a significant change in a lake with time. A secondary objective is to classify the actual state of a lake at a specific time. This section addresses the prime objective. To achieve this, the data on the trophic state variables Chla, SD, TP and TN are deseasonalised before fitting them to a trend line to increase the sensitivity of the trend detection procedure, as is described below. Unfortunately, with the NZLMP data it was not possible to find any change in the phytoplankton data with time, because only one aggregated phytoplankton sample per year was analysed. This was even true of Lake Omapere, which showed a large decrease in trophic level with time. Therefore phytoplankton species biomass is not used as a primary variable in this protocol. The key variables used are: Chla, SD, TP and TN for unstratified lakes; these four variables plus HVOD rates for stratified lakes. Further research is required on phytoplankton data assessment before these data can be used in determining fine-scale trophic level change.

If there are three or more years of data available for a lake, it is possible to carry out a valid deseasonalising procedure on the data. (It is too easy to obtain false trends with only two years of data.) Chla provides a good example of the data analysis procedures used. Figure 1.1. shows the Chla

concentrations observed during four years of monitoring, plotted only as a function of the time of year of collection with no regard for the year of collection. A fourth-order polynomial curve is fitted to these observed data. For each of the days when there were observed data, values calculated using the polynomial are subtracted from the measured data to obtain the deseasonalised residual values shown in Figure 1.2. A non-sinusoidal formulation of the seasonal pattern was chosen because the patterns of

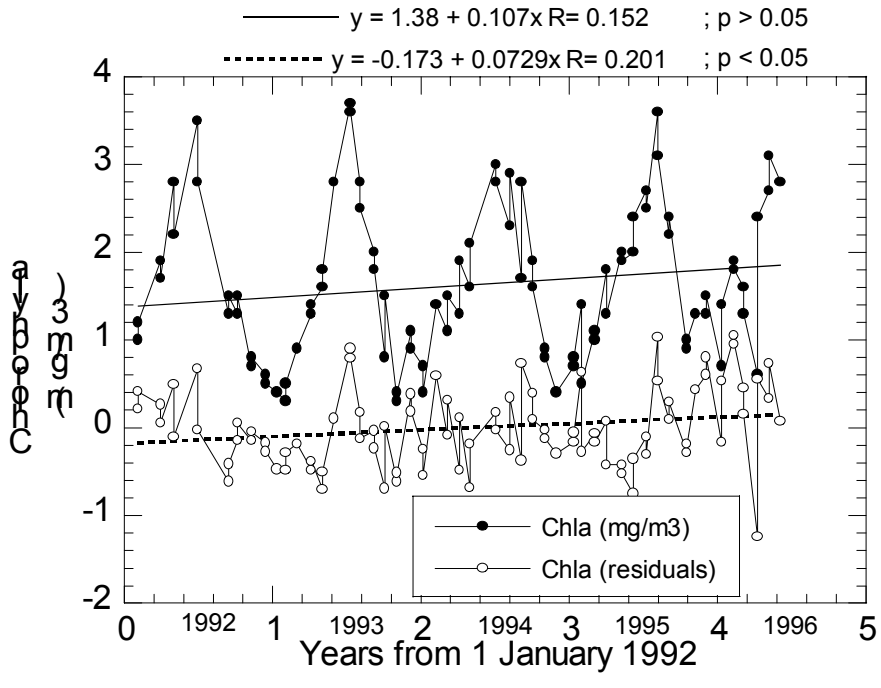


change in Chla, SD, TP and TN with time are frequently irregular.

Figure 1.1: Observed chlorophyll *a* concentrations for Lake Okataina from March 1992 to June 1996

Figure 1.2: Least square linear fits to observed and residual values for Lake Okataina chlorophyll *a* concentrations

Other methods of deseasonalising data can also be used. Average values can be calculated for each month and these values subtracted from values observed in the same month to generate residual values. This technique has been used by Bell and Goring (1998). Another technique is to fit a moving average curve to the annualised data, changing the weighting so that the curve passes optimally



through the points. Considerable judgement is necessary when using this technique to ensure that the curve fit to the annualised data is good.

The observed and residual data are plotted against time in Figure 1.2 and straight-line plots are fitted to the data using ordinary least square regressions. A *p*-value is then calculated for the line fitted to the data. A low *p*-value means that there is a low probability that the fit of the line is attributable to chance; in other words, there is a low possibility of observing a trend at least as large as the value calculated when there is no trend in the data. Since the units along the *x*-axis in Figure 1.2 are years, the slope of the line designates the change per year in the variable.

Removing variability from the data by the deseasonalising procedure enables trends to be determined with more confidence. There is a greater than 5% probability of obtaining an increase in the observed Chla of 0.107 gm m^{-3} per year when there is actually no trend, while with the deseasonalised data there is a less than 5% probability of obtaining an increase of 0.073 gm m^{-3} per year when there is no trend.

Percent annual change (PAC) values are calculated by determining the slope and significance level of the residuals data plot with time for each of the key variables. The slope of the regression line gives the annual change in a variable, and dividing by the average value of the variable during the period of observation gives the PAC value. This is illustrated in Figure 1.2 which shows that the annual change in Chla in Lake Okataina was 0.073 mg m^{-3} $year^{-1}$ which, when divided by the average concentration for the period of 1.63 mg Chla m^{-3}, gives a PAC value of 4.6% $year^{-1}$. The PAC values for the different variables are expressed in the same units and so can be added together to generate an average value, plus a *p*-value for the average, for each lake. Only significant PAC values are included in the calculation of the average PAC value for a lake; non-significant PAC values are given a value of 0.0. The significance level for acceptable trends with time in Chla, SD, TP and TN is a *p*-value < 0.05.

Table 1.1 shows the results of the PAC assessments of four representative lakes with three or more years of monitoring data. The *p*-values of the average PAC values are seen to vary markedly, with the lower *p*-values indicating lakes that have probably changed with time. The average PAC value and its standard error indicates the magnitude of the change that has occurred in a lake. Changes indicating increased eutrophication are assigned positive values and changes indicating decreased eutrophication are given negative values.

Table 1.1: Percent annual change (PAC) values from four representative lakes

Lake	PAC					Average PAC (% $year^{-1}$)	Std error	*p* -value of PAC average
	Chlorophyll	Secchi depth x -1.0	Total phosphorus	Total nitrogen	HVOD			
Hamilton	-10.6	-4.4	-10.8	-16.8		-11	2.5	0.02
Hayes	-24.9	(-1.4)	-8.9	-2.9	(+1.6)	7.4	4.4	0.19
Maratoto	45	7.6	(+0.3)	-11		10	12.1	0.45
Okareka	9.6	5.7	7.1	(-0.3)	(-3.8)	4.5	1.93	0.08

Notes:

The p-value of each PAC average gives the probability that the calculated PAC average could be obtained by chance when its value is actually zero.

Non-significant changes are in brackets.

1.7 A trophic level index for New Zealand lakes

This section addresses the second objective of classifying the actual state of a lake at a specific time and changes in this state with time. Vant has published a list of the four major lake types found in New Zealand in Davies-Colley *et al* (1993, Table 5.5), together with the values of the trophic state variables

associated with each of these lake types, as shown here in Table 1.2. Vant's scheme was considered as a basis for a trophic level scheme for New Zealand lakes but was rejected because it did not contain enough lake types: rather than classifying lakes with Chla concentrations between 5 and 30 mg m^{-3} as similar in nature, it is preferable to have at least two classes of lake in this range of chlorophyll concentration.

Table 1.2: Values of variables defining lake classes

Lake class	Chlorophyll *a* (mg m^{-3})	Secchi depth (m)	Total phosphorus (mg m^{-3})	Total nitrogen (mg m^{-3})
Oligotrophic	<2.0	>10	<10	<200
Mesotrophic	2–5	5–10	10Ğ20	200Ğ300
Eutrophic	5–30	1.5–5.0	20Ğ50	300Ğ500
Hypertrophic	>30	<1.5	>50	>500

Source: Vant, in Davies-Colley *et al*, 1993.

Carlson (1977) and Chapra and Dobson (1981) both proposed trophic state index schemes (shown in outline in Table 1.3), but neither of these schemes seems appropriate to New Zealand lake conditions. Carlson's scheme is based on Secchi depth, with the SD of each new level being half that of the previous level. As a result there can be large increases in the Chla concentrations between trophic levels. In other words, Carlson's scheme is too coarse in its higher trophic levels for local conditions. Chapra and Dobson's scheme is based on Great Lakes data, proposing five levels for the mesotrophic range. This is considered to be too fine a scale for New Zealand lake conditions. Further, as many New Zealand lakes show aspects of nitrogen limitation to growth (White *et al*, 1985), TN becomes an essential variable in a trophic level index scheme for New Zealand lakes and neither Carlson nor Chapra and Dobson included TN in their classification schemes.

As a result of the above considerations, a TLI scheme is proposed here, which is suitable for a wide range of New Zealand conditions. It is based on the Vant scheme but has one more level of lake type for the Chla range of 5–30 mg m^{-3} and it includes TN. Thus trophic level indices of 3, 4 and 6 were assigned to Chla concentrations of 2, 5 and 30 mg m^{-3}. A straight-line plot was then fitted to these points using ordinary least squares (OLS) regression, as shown in Figure 1.3, giving the equation for the trophic level index for chlorophyll *a* (TLc):

$$TLc = 2.22 + 2.54 \log(Chla) \qquad \text{equation (1)}$$

The equation was a good fit to the points, except that a TLc value of 6.0 was found to correspond to a Chla concentration of 31.0 mg m^{-3}. Equation (1) was then used to calculate an annual average trophic level index for Chla from the annual average of the measured Chla concentrations for each lake for each year.

Table 1.3: Values of chlorophyll *a* defining the mesotrophic state of lakes and their corresponding trophic state values, as proposed by different authors

Vant (1987)	Carlson (1977)		Chapra and Dobson (1981)		Burns *et al* (this publication)	
Chla (mg m^{-3})	Chla (mg m^{-3})	Trophic state index values	Chla (mg m^{-3})	Trophic state index values	Chla (mg m^{-3})	Trophic state index values
2.0Ğ5.0	2.6Ğ6.4	4.0Ğ5.0	2.9Ğ5.6	5.0Ğ10.0	2.0Ğ5.0	3.0Ğ4.0
Variables used:						
Chla	Chla		Chla		Chla	
SD	SD		SD		SD	
TP	TP		TP		TP	
TN			Primary production		TN	

Notes:

Carlson's index is based on European and North American lake data (spring TP and summer Chla).

Chapra and Dobson's index is based on spring, summer and autumn data from the Great Lakes.

Burns *et al*'s index is based on annual average data from 24 New Zealand lakes.

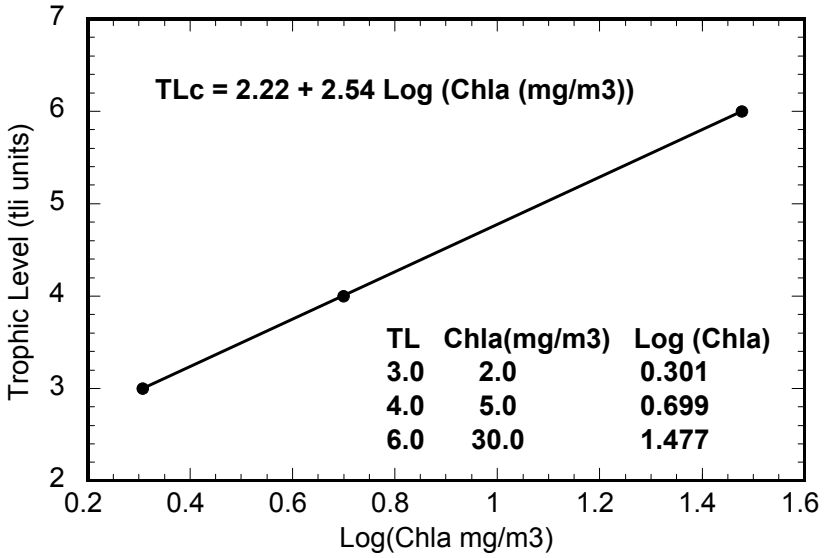


Figure 1.3: Plot of log chlorophyll *a* values against the proposed trophic level index values, with the linear fit to the points and equation to the line

Before the other variables (SD, TP and TN) can be used in the trophic state index, they must be normalised so that they vary over the same range as the index TLc. This was accomplished by deriving regression models between the trophic state index for Chla (TLc) and TP, TN and SD. Annual average measurements were used to derive these regressions, data from all lakes were combined, and data were log transformed prior to analysis. After examining different types of relationships, it was found that TLc against log (SD, TP, TN) produced the most stable relationships. The regressions are shown in Figure 1.4 for 75 annual averages of SD, TP and TN for 24 lakes – 23 NZLMP lakes plus Lake Taupo 1995-1997 (MM Gibbs, *pers comm*). The values for SD were modified, as discussed by Chapra and Dobson (1981), to allow for the absorption of light by water. Crater Lake, one of the world's clearest lakes, has an average SD of close to 40 m, so this value was used to allow for light absorption by water.

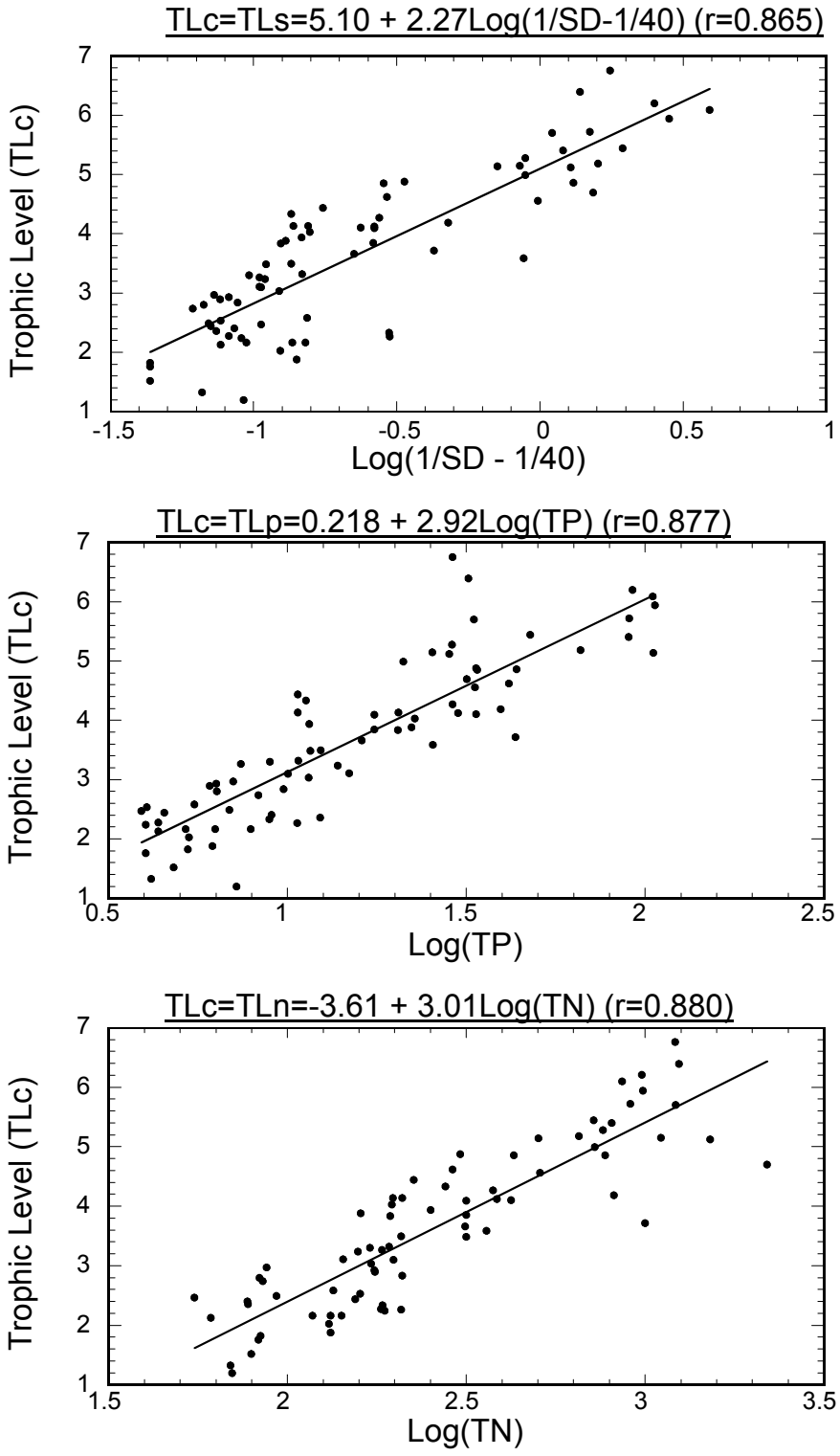


Figure 1.4: Plots of logarithms of annual average values of Secchi depth (a), total phosphorus (b), and total nitrogen (c) against the trophic level index values of the chlorophyll *a* annual average obtained from the same lake in the same year

The regression equations from Figure 1.4 are:

$$TLs = 5.10 + 2.27 \log(1/SD - 1/40) \quad \text{equation (2)}$$

$$TLp = 0.218 + 2.92 \log(TP) \quad \text{equation (3)}$$

$$TLn = -3.61 + 3.01 \log(TN) \quad \text{equation (4)}$$

In each lake for each year these regression models were used to calculate the trophic level indices TLs, TLp and TLn from the annual average of variables SD, TP and TN. Annual average values were used because this effectively deseasonalises the data. The assumption underlying this normalisation is that on average:

$$TLc = TLs = TLp = TLn \quad \text{equation (5)}$$

Indeed, the average values of TLc, TLs, TLp and TLn calculated from the regression equations for all 24 lakes equalled 3.66 TLI units. Each of the trophic level indices is a continuous variable in the range 0–7. We assume that the values 1, 2, 3, 4, 5 and 6 define the boundaries between different trophic levels. For example, a lake with TLc = 3.2 has a lower trophic level than another lake with TLn = 4.1. Table 1.4 illustrates the application of this procedure. If necessary, values of the trophic level variables can be calculated for TLI levels of 8 or higher, although this is not done here. The main reason for developing equation (5) is that it normalises the trophic level indices calculated from SD, TP and TN. This enables the average trophic level index to be calculated:

$$TLI = {}^{1}\!/\!_{4} \, (TLc + TLs + TLp + TLn) \quad \text{equation (6)}$$

Table 1.4: Values of variables that define the boundaries of different trophic levels

Lake type	Trophic level	Chla (mg m^{-3})	Secchi depth (m)	TP (mg m^{-3})	TN (mg m^{-3})
UltraĞmicrotrophic	0.0Ğ1.0	0.13Ğ0.33	33Ğ25	0.84Ğ1.8	16Ğ34
Microtrophic	1.0Ğ2.0	0.33Ğ0.82	25Ğ15	1.8Ğ4.1	34Ğ73
Oligotrophic	2.0Ğ3.0	0.82Ğ2.0	15Ğ7.0	4.1Ğ9.0	73Ğ157
Mesotrophic	3.0Ğ4.0	2.0Ğ5.0	7.0Ğ2.8	9.0Ğ20	157Ğ337
Eutrophic	4.0Ğ5.0	5.0Ğ12	2.8Ğ1.1	20Ğ43	337Ğ725
Supertrophic	5.0Ğ6.0	12Ğ31	1.1 Ğ0.4	43Ğ96	725Ğ1558
Hypertrophic	6.0Ğ7.0	>31	<0.4	>96	>1558

TLI time trend values can be calculated (using OLS regression) from either the individual values of TLc, TLs, TLp and TLn or for the annual average TLI from equation (6). The individual values must be used if the changes in TLc, TLs, TLp and TLn with time are not either all increasing or all decreasing. This gives the change in the TLI in TLI units per year, with a *p*-value calculated for the slope of the regression line (as in Figure 1.5 for Lake Okareka).

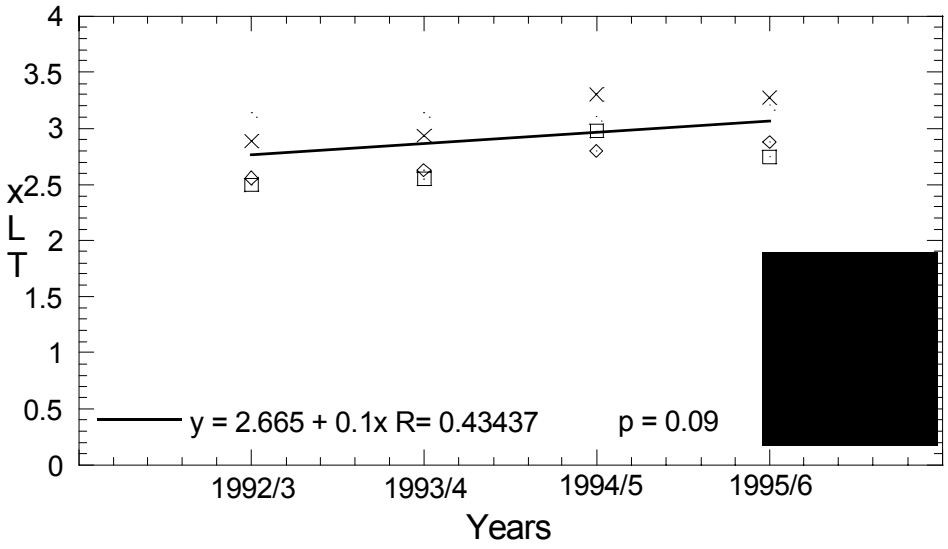


Figure 1.5: Plot of Lake Okareka TLx values against years with an OLS regression fit to determine the TLI time trend line

The results of the TLx and TLI calculations for four representative lakes in the study are shown in Table 1.5. The change in the TLI values with time (TLI trends) were calculated for lakes with three or four years of observational data. (The normal September to August lake year was not used in these instances to enable calculation of four annual averages from data collected from March 1992 to June 1996.) The actual TLI value for a lake is calculated from the two most recent years of data for the lake because the TLI values for some of the lakes can change rapidly.

Table 1.5: Annual averages, TLI values and TLI trends with time for four representative New Zealand lakes

Lake	Period	Chla ($mg\ m^{-3}$)	SD (m)	TP ($mg\ m^{-3}$)	TN ($mg\ m^{-3}$)	TLc	TLs	TLp	TLn	TLI Av	SE TLI av	TLI trend units $year^{-1}$	SE TLI trend	*p* -value TLI trend
Hamilton	Apr 92ĞMar 93	23.39	0.89	33.2	1216	5.70	5.20	4.64	5.68	5.30	0.25			
	Apr 93ĞMar 94	14.26	1.14	25.4	1107	5.15	4.94	4.31	5.55	4.99	0.26			
	Apr 94ĞMar 95	15.98	1.09	28.8	763	5.28	4.98	4.46	5.07	4.95	0.17			
	Apr 95ĞMar 96	12.35	1.09	21.1	722	4.99	4.98	4.07	4.99	4.76	0.23			
	Averages	16.50	1.05	27.1	952	5.28	5.03	4.37	5.32					
Hamilton Lake two-year TLI value (1994Ğ96) : TLI time trend (1992Ğ96)										*4.85*	*0.16*	*-0.16*	*0.1*	*0.1*
Hayes	Aug 92ĞJun 93	10.91	3.23	33.8	430	4.86	3.86	4.67	4.32	4.43	0.22			
	Aug 93ĞJun 94	5.51	3.82	33.7	422	4.10	3.68	4.66	4.29	4.18	0.20			
	Aug 94ĞJun 95	5.59	3.46	30.0	384	4.12	3.79	4.51	4.17	4.15	0.15			
	Aug 95ĞJun 96	6.39	3.34	29.0	376	4.27	3.83	4.47	4.14	4.18	0.14			
	Averages	7.10	3.46	31.6	403	4.34	3.79	4.58	4.23					
Lake Hayes two-year TLI value (1994Ğ96) : TLI time trend (1992Ğ96)										*4.16*	*0.11*	*-0.8*	*0.8*	*0.3*
Maratoto	Apr 92ĞMar 93	13.90	0.77	28.3	1517	5.12	5.34	4.44	5.96	5.22	0.31			
	Apr 93ĞMar 94	9.45	0.64	31.7	2194	4.70	5.52	4.59	6.45	5.31	0.43			
	Apr 94ĞMar 95	43.96	0.71	32.1	1241	6.39	5.42	4.60	5.70	5.53	0.37			
	Apr 95ĞMar 96	61.20	0.56	29.0	1211	6.76	5.66	4.47	5.67	5.64	0.47			
	Averages	32.13	0.67	30.3	1541	5.74	5.49	4.53	5.95					
Lake Maratoto two-year TLI value (1994Ğ96) : TLI time trend (1992Ğ96)										*5.58*	*0.33*	*0.15*	*0.16*	*0.38*
Okareka	Jul 92ĞJun 93	1.84	9.88	6.1	175	2.89	2.56	2.50	3.14	2.77	0.15			
	Jul 93ĞJul 94	1.90	9.36	6.3	175	2.93	2.63	2.55	3.14	2.81	0.14			
	Jul 94ĞJun 95	2.67	8.22	8.9	170	3.30	2.80	2.98	3.11	3.05	0.11			
	Jul 95ĞJun 96	2.58	7.70	7.4	184	3.27	2.88	2.75	3.21	3.02	0.13			
	Averages	2.25	8.79	7.2	176	3.10	2.72	2.69	3.15					
Lake Okareka two-year TLI value (1994Ğ96) : TLI time trend (1992Ğ96)										*3.04*	*0.09*	*0.1*	*0.05*	*0.09*

Abbreviations:

TLc = the trophic level value calculated from the Chla annual average.

TLs = the trophic level value calculated from the SD annual average.

TLp = the trophic level value calculated from the TP annual average.

TLn = the trophic level value calculated from the TN annual average.

SE = standard error; av = average.

.

1.8 Removing weather effects

In some shallow lakes, sediment disturbance by wind-induced turbulence is a stronger process than change caused by seasons: in other words, weather phenomena dominate over seasonal ones. In these cases, the lake data need to be 'deweathered' rather than deseasonalised. Inorganic suspended material (ISS) concentrations increase with increasing wind because the wind-induced turbulence of the lake water can resuspend large amounts of sedimented materials. One way to remove the effects of wind from monitoring data is to look for a relationship between the key variables and ISS, and to use this relationship to find residual values of the key variables after allowance has been made for their content of ISS. Figures 1.6 and 1.7 are examples of this procedure applied to Lake Omapere data. Figure 6.4 shows a map of this lake.

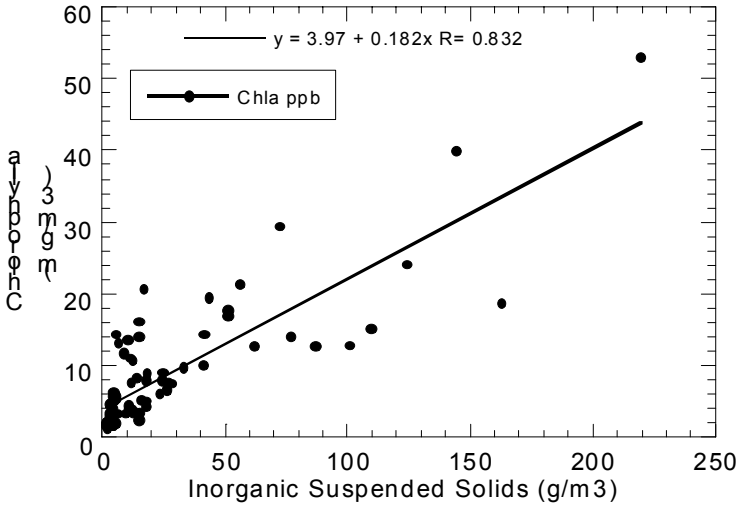


Figure 1.6: Plot of Chla against ISS for Lake Omapere from December 1993 to June 1996

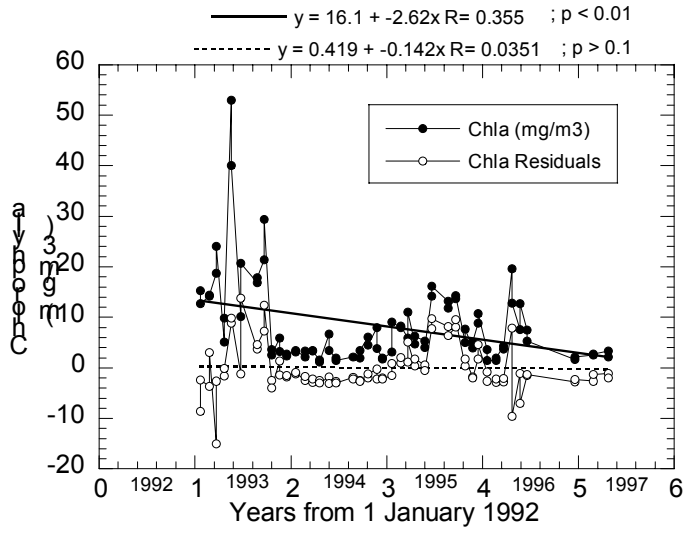


Figure 1.7: Plot of observed Chla data and Chla residuals after adjustment for their ISS content

1.9 Determination of change of trophic level

The similarity of the PAC values obtained for a lake from its different variables (four from the shallow lakes and five from the stratified lakes) is demonstrated by the *p*-value of the average PAC value. Low *p*-values indicate similar PAC values making up its average, in much the same way as a low standard error of the average does. Since consistent change between the variables of a lake is taken as evidence of change in the lake, the *p*-value of the PAC average allows an estimate to be made of the probability of change according to the scheme shown:

p-*value range of PAC average*

< 0.1: definite change

0.1–0.2: probable change

0.2–0.3: possible change

> 0.3: no change

The TLI time trend values (Tables 1.5 and 1.6) also give an indication of the change of trophic level in a lake. A comparison of the results of the TLI and PAC methods is shown in Table 1.6, and shows good qualitative agreement. The PAC value is better to use in deciding whether a lake has changed trophic level or not, because it can use five different variables and the data are not condensed to a few numbers before analysis. The observed and residual data plots (Figure 1.2) enable a good look at the actual data obtained for analysis, which is not possible when annual averages are used for calculation of TLI values. However, although the PAC value gives an estimate of the degree of change that may be happening, it is only a relative measure and difficult to utilise. The TLI value, on the other hand, gives a clear idea of the actual state of the lake and a useful estimate of the degree of change that a lake may be undergoing in TLI units. The two indicators are most effective when used together.

Table 1.6: Comparison of TLI values and time trends with PAC values for four representative lakes

Lake	TLI value		PAC average			TLI trend			Conclusions about change
	TLI units year^{-1}	SE	% year^{-1}	SE	*p* -value	TLI units year^{-1}	SE	*p* -value	
Hamilton	4.76	0.11	-11	2.5	0.02	-0.16	0.1	0.1	Definite improvement
Hayes	4.16	0.09	-6.9	4.4	0.19	-0.08	0.08	0.3	Probable improvement
Maratoto	5.58	0.27	10	12.1	0.45	0.15	0.16	0.38	No change
Okareka	3.04	0.08	4.5	1.93	0.08	0.1	0.05	0.09	Definite deterioration

Notes:

The guide used in the PAC average *p*-value evaluation is:

< 0.1: definite change

0.1–0.2: probable change

0.2–0.3: possible change

> 0.3: no change

SE = standard error.

Chapter 1 has outlined the concepts used in this protocol on lake monitoring and illustrated them with results obtained from their use in the New Zealand Lakes Monitoring Programme. Some of the ideas and results shown in this chapter will be presented again in greater detail in subsequent sections. The following chapters will delve into the practical detail necessary to implement these concepts effectively.

Chapter 2: Sampling techniques and equipment

Good sampling technique on the lake is essential. Laboratory and data analysis techniques may be excellent, but unless the on-lake work of measuring profiles, selecting sample depths and taking clean samples is done well, the whole monitoring exercise will fail. Good equipment is also essential. Weather conditions often frustrate lake sampling plans and diminish the number of samplings, but a reliable boat and equipment will enable sampling to be carried out that otherwise might have been cancelled. Inevitably it is the vital information that is lost when weather prohibits sampling or equipment fails.

2.1 Selection of a boat

Selection of a boat appropriate to the lakes being sampled is one of the main factors making correct and efficient sampling possible. The choice is governed by the following factors:

Economy

Even basic boats are expensive. Monitoring programmes cost a lot of money, and as labour is a significant component, the faster that the samples can be taken and processed the better. Also, accidents can be extremely expensive. The extra money spent at the beginning of a programme on the appropriate boat will pay dividends in the long term by ensuring safe and efficient working conditions.

Workspace

Working in a cluttered boat increases the potential for things to go wrong.

Storage area on board

At times a large amount of sampling gear will be carried, especially if a large number of sites are to be visited in the same day. Good storage space is important if work is to be carried out quickly and efficiently.

Weather conditions

The boat must handle the worst conditions it is likely to encounter if caught out by a sudden change of weather. The boat must also provide adequate shelter: cover from the rain and the sun is necessary, especially if long hours are to be spent on the water and sampling during winter is required.

Towage

The boat must be easily towed by its vehicle (the appropriate mass ratios of the towing vehicle to the towed mass are well documented). The vehicle must always be able to control the towed boat, especially when the brakes have been applied suddenly.

Buoyancy

The boat must contain positive buoyancy to ensure that it floats if overturned or swamped.

Handling

The boat must be manageable by those people most likely to be using it and in the places it will be used. Its size, shape and weight must be considered.

Input of local knowledge from experienced personnel is essential when selecting the craft to be used in local waterways. A dinghy may be suitable for a smaller lake, but on some bigger lakes a larger, faster craft is needed to ensure that the work is completed, especially when a large number of sites need to be sampled. So the vessel must be selected with the complete programme in mind.

2.2 Basic safety

Most basic safety precautions are highlighted in a number of excellent boating safety manuals currently in circulation, such as *Safety in Small Craft* (Scanlan, 1994). This, coupled with the provisions of the Health and Safety Act, should ensure that the work is carried out in a safe and efficient manner.

The most important point is that all personnel should have boating knowledge and experience, especially with the type of vessel being used. At least two people are required for all on-lake work. The driver has to have the relevant experience to operate the craft and all crew should complete a basic boating safety course. The crew must have a rudimentary knowledge of boat handling, first aid, fire extinguisher use and the emergency equipment carried on the boat. Life-jackets need to be worn. Traditional life-jackets are too bulky to work in, but modern jackets or buoyancy aids are not generally bulky and can be worn all day without discomfort. Inflatable jackets are also available. The use of survival suits should be considered when sampling dangerously cold waters.

A daily sampling plan should be left at base with an expected time of return. Contact should be kept with radio telephones or cellphones switched on. It is important to keep in touch with weather forecasts. The boat needs to be regularly serviced and someone should be allocated the responsibility for this. A boat log should be filled out at the end of each trip to indicate any maintenance required. It should show who has driven the boat, where it went, and when it was filled with petrol and serviced.

2.3 Positioning on the sampling station

Sampling sites or stations will be chosen by the project leader from current bathymetric maps. One of these sites should be close to the deepest part of the selected lake. The first visit should be used to investigate the suitability of the sampling station. Once a sampling station has been selected, it is important to make sure that the site is sampled in the same place on all subsequent visits. Using permanent landmarks and a good-quality depth sounder on smaller lakes will get the boat reasonably close to the same spot on each visit, and this becomes easier with experience.

On larger lakes more care is needed for accurate positioning. A global positioning system (GPS) can be used but, unless it is a differential system, may give only a rough position because of the corrections applied to the satellites. However, a GPS in combination with a good set of landmarks will ensure that the same spot is found on all visits. A set of photographs taken on the first visit can also help to locate the sampling spot.

The most practical solution to the problem of returning precisely to the same site is to place a permanent buoy on the sampling site, but this is not always possible. Some lakes have high use, especially in the summer, by fisherman, yachtsmen, water skiers and general boating traffic. Permanent buoys regularly go missing when placed on some of the country's more popular lakes. Temporary buoys can be used to help anchor the boat in the correct position, especially if there is a wind. Once the spot is located, the temporary buoy can be dropped. The boat can then be driven into the wind away from the buoy and, once the anchor is dropped, allowed to drift back until it is nearly at the temporary buoy, when the anchor rope can be tied off.

It is important to anchor at the sampling station and not drift around it. Since most of the anchoring required for lake sampling is over silt bottoms, a good-quality Plough, Danforth, Kewene or similar type of anchor is needed. A Kewene anchor is a popular choice, as there seems to be less chance of this anchor tangling in its chain. This can happen when the chain sinks faster than the anchor, but can be avoided by letting the anchor down in a controlled fashion, rather than throwing the anchor and chain overboard and letting it sink under its own weight. It is most annoying to have to abort a sampling and re-anchor because the anchor has tangled in its chain and did not hold. A sufficient length of chain needs to be added. The rule of thumb is that the chain should be as long as the boat being anchored. This allows the anchor to set at the right angle to ensure a good hold on the lake bed. Good quality anchor rope should be used and be at least twice as long as the deepest site over which the boat will be required to anchor. The rope should be supple enough to coil easily into an anchor well or container when retrieved. Anchor retrieval after sampling at a deep station can be made

relatively painless by using one of the large selections of anchor-retrieval systems currently on the market. These mainly consist of one-way clips attached to buoys. The anchor rope slides through the one-way clip lifting the anchor towards the buoy and remains there, allowing the anchor rope to be pulled easily on board. The instructions for using this kind of equipment need to be followed for safety.

2.4 Sampling equipment required

This section describes the use, purpose and care of each item in the list below:

- dissolved oxygen/temperature meter
- cable
- weight
- probe
- mixing containers for DO calibration
- thermos flask
- Van Dorn sampler and Van Dorn messenger unit
- spare Van Dorn rubber
- Secchi disc
- Secchi disc viewer
- chilly bins and ice
- sample bottles
- large mixing container
- funnel
- temporary buoys
- depth sounder
- field sheets and instructions
- sponges and plastic bags
- sample identification numbers
- important spares.

The dissolved oxygen/temperature meter

The YSI model 58 with stirrer gives a digital readout of DO and temperature. It pays to wrap the meter in bubble plastic or something similar between readings to protect it from knocks and direct sunlight. The digital read-out screen sometimes goes dark when exposed to sunlight for long periods, especially on some older meters. These meters will give consistent high-quality readings for a long period if they are well looked after. Other DO/temperature probes are available, such as the Minisonde probe produced by Hydrolab (Associated Process Controls (APC), *pers comm*).

Cable

The cable is the interface between the DO meter and the DO probe. It has to be of sufficient length to reach the bottom of the deepest site. This may mean that cables need to be spliced. Cables supplied by YSI come in 75-m lengths. Joining or splicing of cables must be carried out by persons experienced in this work. The joints need to be of a high quality because of the low-voltage signals generated. The cable must be clearly marked and have a stirrer attached. Cables should be stored in a good strong

plastic bin, preferably with holes in the bottom to drain out water and with enough room to store the cable without causing sharp bends in it.

Weight

A weight is attached to the cable and allowed to hang below the probe and stirrer. This should be of sufficient length to prevent the probe lying on or in the sediments and thereby giving an unusually low DO reading. It is recommended that the weight be allowed to hang exactly 1 m below the probe. When the weight hits the bottom, one m is added to the reading on the cable and that measurement becomes the maximum depth. The bottom DO and temperature readings are then taken one m from the bottom.

Probe

The YSI 5739 probe sends weak electrical signals up the cable to the meter, which interprets these signals as DO concentrations or temperatures.

Mixing containers for DO calibration

These must be of a reasonable size, so that water can be poured from one to the other to prepare air-saturated water for the field calibration of the DO meter (2.5-litre containers are satisfactory).

Thermos flask

This is needed to help calibrate the DO before each profile is carried out using the air-saturated water.

Van Dorn sampler

This instrument is used to take water samples at different depths. It is basically a tube with a rubber bung at each end and a trigger mechanism to close the bungs when the messenger strikes the sampler at the appropriate depth. The Van Dorn sampler must be attached to a good-quality rope which should be clearly marked at 1-m intervals. The messenger is attached to the rope and slides down it, striking the Van Dorn trigger mechanism and closing the rubber bungs at each end of the sampler. This rope should be stored in a large fish bin or similar container with drainage holes in order to keep it from tangling.

Spare Van Dorn rubber

At least one spare rubber connector for the Van Dorn sampler should be carried as rubbers tend to deteriorate – more with time than with actual use. If the rubber connector breaks, it will do so while sampling is taking place and the rubber bungs will be lost. It takes only a few minutes to change the rubber connectors so this component should be checked frequently.

Secchi disc

This is a round disc 200 mm in diameter, painted black and white. The Secchi disc is used to estimate the photic depth in lakes. The disc is attached to either a rope or a fibreglass tape. The rope or tape should be clearly marked to the nearest centimetre. Fibreglass tapes delaminate, but they have the advantage of being already marked when purchased.

Secchi disc viewer

The Secchi disc viewer is basically a waterproof black box with a clear plastic end. It is used to look into the water by placing the clear end in the water and is especially useful when the lake surface is ruffled. It should always be used to help produce consistent SD results. The viewer must be clean, with no leaks or scratches on the bottom surface.

Chilly bins and ice

The chilly bins must be of a sufficient size to hold all water samples and ice. This is very important in summer when lake water temperatures are high. Water samples have to be cooled as soon as possible after they are taken.

Sample bottles

A range of sizes from 1 litre to 5 litres will need to be carried. They can be prelabelled as the sample numbers may not vary much from year to year.

Large mixing container

This is used to mix the composite sample from the epilimnion when the lake is stratified, or to mix the top sample when the lake is isothermal. It should be of sufficient size (20 litres is ideal) to hold and mix the maximum amount of water sample that will be taken. A large mouth will also assist in transferring the samples into the container, especially if the lake is a little choppy.

Funnel

This is useful for transferring water from the Van Dorn sampler to the large container or from the large container to the smaller sample bottles. It needs to be large so that transfer of water is quick and trouble free. The funnel must be rinsed thoroughly before each transfer to prevent contamination of the water sample. It must be stored dry and protected so that risk of contamination is minimal. A plastic bag is ideal.

Temporary buoys

Temporary buoys may be needed to mark a sampling spot and can be stored in their own fish bins with the exact length of rope needed for each site where they will be used. Their use will depend on the weather on the day of sampling.

Depth sounder

A depth sounder is essential if the same position for a station is to be found and sampled. The sounder is part of the basic equipment of the boat. It must be of good quality and able to accurately record to the depths likely to be encountered.

Field sheets and instructions

Sufficient numbers of field sheets need to be taken to complete the day's work. These should be printed on waterproof paper and stored in a plastic bag or waterproof container with clipboard, pencils and instructions. It is also recommended that a copy of the field sheets from the previous sampling run be carried, as these can be extremely useful when trying to determine the depth of the epilimnion and hypolimnion layers. They are also useful when staff are being trained. Waterproof paper is readily available from most surveying suppliers.

Sponges and plastic bags

Sponges in sealable plastic bags are recommended for the storage of the DO probes when not in use. The sponges are moistened and the DO probe wrapped in the sponge and then placed in a plastic bag. The plastic bag is then sealed to prevent the DO probe from drying out.

Sample identification numbers

There needs to be sensible labelling of the sampling sites so that all samples are easily traceable.

Important spares

Glands, KCl solution, scissors (fly-tying scissors are suitable) are needed for the DO meter probe. Allen keys for the Van Dorn sampler should be carried and stored in a waterproof plastic container. A gland-changing register is also handy to have for recording probe serial numbers and the dates of gland changes.

2.5 Calibration and cleanliness of sampling equipment

An important part of quality assurance is ensuring that all equipment is clean and measuring correctly. Regular calibration of equipment is essential. This maintenance of sampling equipment can be divided into:

- annual calibration checks
- calibration before a field trip
- calibration at the sampling station
- cleanliness of equipment.

Annual calibration checks

Annual calibration of equipment includes the following.

Thermometer checks

The YSI meter temperature measurement system should be adjusted to conform with temperatures measured at 0°C and 35°C as determined by a standard thermometer.

Sulphide checks of the dissolved oxygen zero

Measure the meter zero-error by setting the meter to zero with the zero knob, then taking the oxygen concentration reading in sodium sulphite solution (1 g in 500 ml water) with the stirrer on. This value is the meter zero-error. Readings below 20% saturation (sat) DO should be corrected by subtracting the meter zero-error from the reading. This adjustment should be less than 3% sat DO.

Markings of length

Markings on all cables, tapes and ropes used to measure depth or take samples at depth should be checked against a survey tape.

Staff gauges

All staff gauges measuring lake level should be checked annually against known benchmarks. For most regional councils and government departments this is part of the annual site inspection.

Deep freeze

Freezer temperature should be checked with a thermocouple and appropriate meter. The freezer should be able to hold frozen Chla filter papers at a temperature below -16^{o}C. Most deep freezers operate below -20^{o}C. This check is only necessary if Chla samples are held for a time before being sent to the laboratory.

Calibration before a field trip

Usually a visual examination is all that is required for the majority of the sampling gear. Any faults should have been rectified after the last sampling run.

Temperature checks

The temperature measurement capability of the temperature/DO meter must be checked. This should be done at two temperatures that will approximate the upper and lower ranges of the temperatures likely to be encountered. Any difference in temperature between the standard thermometer and the DO meter will have to be noted on the field sheet. The temperature data recorded in the field will then have to be adjusted using this correction. Experience has shown that the temperature calibration usually does not vary at all and remains stable for long periods of time. There is no reason for the temperature not to be correct to within $\pm$ 0.1^{o}C if the temperature meter is correctly calibrated.

DO probe

The DO probe gland should also be checked at this time for bubbles, wrinkles or any damage to the membrane. The gland should be replaced if any of the above problems are evident, as this will affect the performance of the DO probe.

If all of the equipment is maintained regularly, then checking and calibration before each field trip should be minimal. The DO meter should be turned on at the beginning of the day and left on until the last sample of the day is taken. Sufficient time should be allowed for the DO probe to consume the oxygen that has been absorbed through the membrane.

Calibration at the sampling station

Once the boat is in position at the sampling spot only the DO meter will need calibrating. This is done before each profile is taken. A sample of air-saturated lake water is prepared by pouring water from one container to another at least 20 times. This water is then poured into a thermos flask to keep it at the same temperature while the profile is measured. The DO probe is placed in the thermos flask and the stirrer turned on. The probe readings should be stable before the temperature is taken. The probe is then calibrated to 100% sat DO. The altitude correction value on the back of the DO meter must be entered onto the field sheet (*see also* section 4.4). Once the vertical profile has been completed, the calibration of the meter is rechecked in the thermos flask. If the calibration differs by more than 3% sat DO, the meter will have to be reset and the profile repeated. This will usually only happen if there has been some delay in completing the profile or if the meter was not set up properly. It may also be the first indication that the probe needs servicing, or that the gland and KCl fluid need changing.

Cleanliness of equipment

A high standard of cleanliness is required at all times. The concentrations of some nutrients are so low that even minimal levels of contamination may render a sample unusable. Equipment must be stored in a clean environment and kept away from likely sources of contamination during use – for example, petrol and oil containers. Storage in plastic bags to minimise contamination is recommended.

All sample bottles must be rinsed, and then shaken to remove as much of the excess rinse water as possible, before the sample is taken. Sample bottle lids should be held clear of any surfaces and the inside of the lid should not be touched. Sampling bottles dedicated to the lakes programme only are to be used. If the origin of any sample bottles is not known then these bottles must not be used.

2.6 Field sheets and sampling procedures

Field sheets

All sampling information is contained in a comprehensive field sheet. The field sheet is basically a simple flow sheet of decisions to be made while sampling each lake. An example of such a field sheet is shown in Figure 2.1. When the field sheet is complete, a good overview of the day's results and the quality checks is achieved. The whole sheet should have been completed by the end of the day.

Field data sheet for lakes

Lake name …….. Site code …….. Field party area ……
Field operators' names …… Day …… Date ……
Lake height …… Time (NZST) …… Lake altitude …… (m)
Secchi disc depth (± 0.01 m) Obs 1 …… Obs 2 …… Mean …… (m)

DO/T meter profiling checks

Date of zero DO check with sulphite …… Observed value …… mg litre^{-1}
Meter zero check ……(tick) Altitude factor: …… Correct data sheet: ……. (tick)
DO water calibration (aerated lake water): Saturated water: Temp …… DO 100 % sat
After completed profile: Saturated water: Temp …… DO ……% sat
Difference should be less than 3% sat

Depth – Temperature – DO profile

Date of last temperature check ……
Lower glass thermometer temp …… Corresponding meter temp ……
Upper glass thermometer temp …… Corresponding meter temp ……
Note: Temp. must be corrected every three months. Difference not to exceed 0.1^{o}C
Record temperature/DO data on profile sheet. Also graph depth/temperature/DO profile.
Maximum water depth ……m

Sampling depths

Is lake isothermal? (Guideline: is subsurface temperature within 3^{o}C of the bottom temperature?) …….YES / NO
If YES:
Collect a 1-litre and a 5-litre sample at $^{1}/_{4}$ of the lake depth (three Van Dorns).
Take a second 1-litre (only) sample at $^{3}/_{4}$ of the lake depth; however, if DO values less than 3% sat are encountered, replace the 1-litre sample at $^{3}/_{4}$ of the lake depth with a sample taken in the middle of the less than 3% sat DO zone (X, for anoxic).
Sampling depths are: …….. m (ISO-T) and ……. m (ISO-B or ISO-B/X)
If NO and lake is stratified proceed as follows:
1 Select thermal layer depths ('knees') at
bottom of epilimnion (epi) …… m
top of hypolimnion (hypo) …… m
Mix four Van Dorn samples as follows: one surface and three equally spaced depths to a maximum of $^{3}/_{4}$ depth of the epilimnion.
2 Epi sampling depths are: 0.2m $^{1}/_{4}$ = …….. m $^{1}/_{2}$ = ……... m $^{3}/_{4}$ …….. m
(Code EPI)
3 From profile, estimated top of hypolimnion (its knee) is at …….. m
Hypo sampling depth is: …….. m
Take a Van Dorn sample at $^{1}/_{2}$ the depth between the hypolimnion knee and the lake bottom. Fill a 1-litre bottle. However, if a less than 3% sat DO region is encountered, take a bottom sample in the middle of this region and keep the two samples separate.
4 Anoxic hypo sampling depth is: …….. m
Codes are HYP for the upper hypo sample and HYP-B/X for the lower hypo sample if a less than 0.3 mg litre^{-1} region is found.

Phytoplankton

Take 100-ml sample from each EPI or ISO-T sample and place in Elkay with 1 ml Lugol's soln.

Figure 2.1: An example of a field data sheet for lake sampling

Secchi disc procedure

The first step when sampling is to set up the DO meter as described above. While the DO meter is acclimatising in the thermos flask, the Secchi disc readings can be taken and recorded on the sampling sheet. The Secchi disc should have sufficient weight to ensure that the disc and the marked line holding it hang vertically in the water. The disc should be lowered into the water on the sunny side of the boat and viewed with the underwater viewer until it just disappears. This distance is noted to the nearest centimetre. The disc is then raised towards the surface until the disc just reappears. This distance is also noted. The vertical sighting range is the average of the distance at which the disc just disappears and the distance at which the disc reappears. The mean depth from the two observations is recorded on the data sheet. The two observations should agree within 10 percent of each other.

Dissolved oxygen and temperature profiles

Once the SD has been measured, the DO and temperature (T/DO) profile can be taken. The spacing of the measurement intervals will depend on the state of the lake. If the temperature and DO profile values are changing then the spacing will be every metre, or every 0.5 m in the thermocline region, for example. The measurement intervals in the hypolimnion should be kept as regular as possible to enable easy calculation of the hypolimnion average DO value. This can be standardised after the first few profiles have been taken. Spacing can be several metres apart if the lake is isothermal with constant temperature and DO. Experience and some knowledge of the lake system help in making such a judgement.

The probe has to stabilise at each depth before the reading can be taken. Then the probe is lowered to the next depth and the reading repeated. The bottom of the lake is reached when the weight hits the bottom leaving the probe 1 m above it. This avoids dropping the probe into the lake sediments, which could cause anoxic sediments to temporarily poison the probe. Once the DO cable is returned to the surface, the DO meter's calibration is checked. As the profile is being taken, the results can be recorded and also graphed. If numerous lakes have to be sampled regularly specific sheets for each lake can be made up with the depth scale entered but the temperature scale left blank for selection on the lake. Figure 2.2 provides examples of such prepared field sheets. It is important that these graphs are accurate and reasonably clear because all sampling decisions will be based on the information shown on these graphs.

After the profile has been completed a decision has to be made as to whether the lake is isothermal or stratified. If the surface and bottom lake temperatures are within 3^{o}C the lake is probably isothermal. However, this is only a guideline. Sometimes in the autumn, the near-surface and near-bottom waters are very similar in temperature but different in DO levels. In this case, the lake should be considered as stratified. In the spring, the lake can be unstratified but with temperature differences greater than 3^{o}C because of rapid warming of the surface waters.

Temperature profiling data sheet for lakes

Lake name …….. Site code …….. Field party area ……
Field operators' names …… Day …… Date ……

Depth (m)	Temperature (^{o}C)	DO (% sat)	Depth (m)	Temperature (^{o}C)	DO (% sat)

Figure 2.2 (a): An example of a temperature/DO profiling data sheet for lake sampling

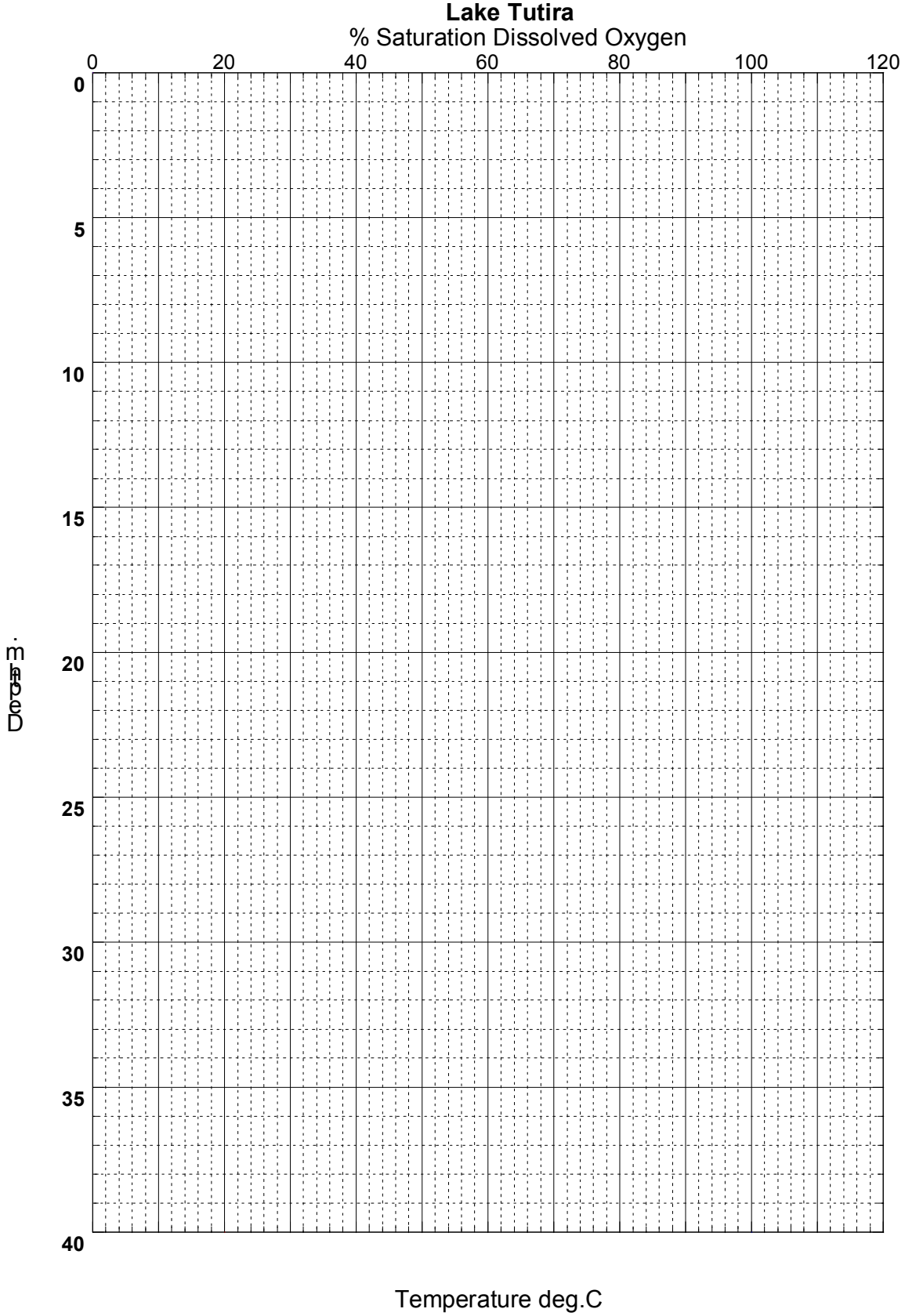


Figure 2.2 (b): An example of a sheet for graphing the temperature and DO profiles. The temperature scale can be filled in according to the temperatures prevailing on the day of measurement

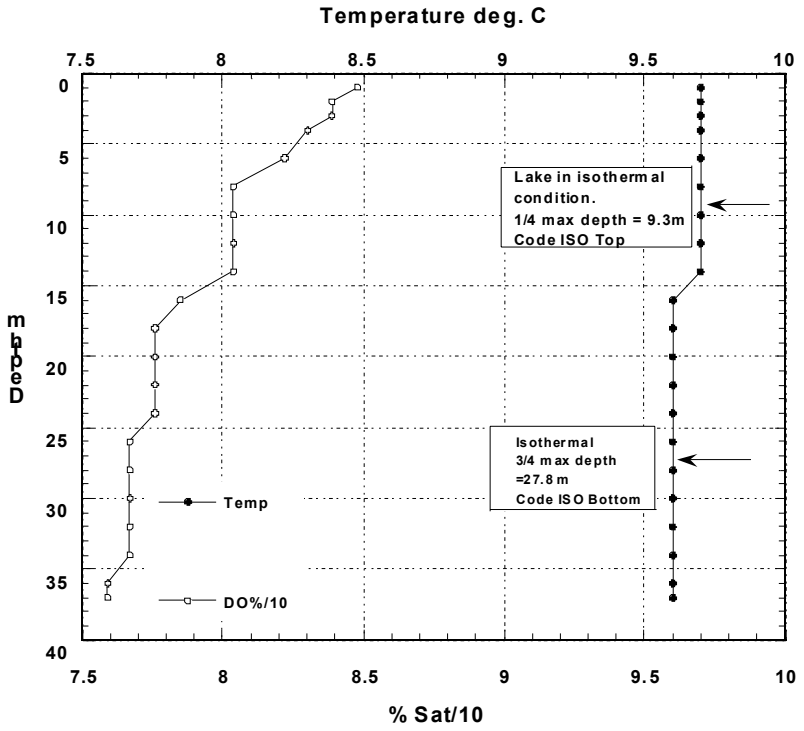


Figure 2.3 (a): Sampling depths for a lake in the isothermal condition

Isothermal lakes

If a lake is not stratified sampling is straightforward. Samples are collected at one-quarter and three-quarters of the maximum depth using the Van Dorn sampler. Figure 2.3 (a) shows a diagrammatic representation of the sampling regime for an isothermal lake.

At the one-quarter-depth point, three 2.2-litre samples are taken and combined in a rinsed 20-litre container. This sample is well mixed by shaking and then subsampled into a rinsed 1-litre sample bottle and a rinsed 5-litre bottle. These sample bottles should be rinsed with surface lake water. The 1-litre subsample is used for nutrient analysis; the contents of the 5-litre bottle are later split into a 100-ml sample used for phytoplankton determination and the remainder is used for Chla analysis. The sample is labelled with the lake name, site code, date and the code "ISO-T". This will prevent the sample from becoming confused with the sample taken from the lower depth.

The following procedure is used for the lower sample. After a single collection by the Van Dorn sampler at the lower sample point, some of the contents are used to rinse a 1-litre sample bottle, which is then filled for nutrient analysis. One litre is an adequate volume because no Chla or phytoplankton samples are taken from the lower depth. The sample is labelled with the lake name, site code, date and the code "ISO-B".

If the bottom waters are anoxic – the rule of thumb for the operational definition for anoxia is a reading of less than 3% sat DO – the lower sample point is changed to account for possible probe errors in low-saturation waters. It is most unusual for isothermal lakes to have anoxic layers, but this can happen, as in the case of Lake Rotorua. When it does, it is important to know whether anoxic regeneration of nutrients has occurred. Therefore the lower sample is taken for nutrient analysis in the middle of the anoxic layer and the sample is transferred to a 1-litre sample bottle as outlined above and coded "ISO-B/X". All the above samples must be stored in chilly bins on ice as soon as they are taken.

Stratified lakes

If the lake is stratified a different sampling procedure is followed, as illustrated by Figure 2.3 (b). Selection of layer depths is not easy and requires both experience and familiarity with the lake being sampled. The sampling personnel have to use their best judgement while on the lake to select the knees – the depths where one layer changes and becomes another. A stratified lake consists of three layers. The top layer is the epilimnion layer, which is the layer of relatively well mixed water above the 'bottom-epi' knee. Below this knee, the near-isothermal waters of the epilimnion change temperature rapidly with depth in the layer known as the thermocline. The 'top-hypo' depth is selected as that depth where the thermocline becomes the hypolimnion, the deeper zone of slower change of temperature with depth.

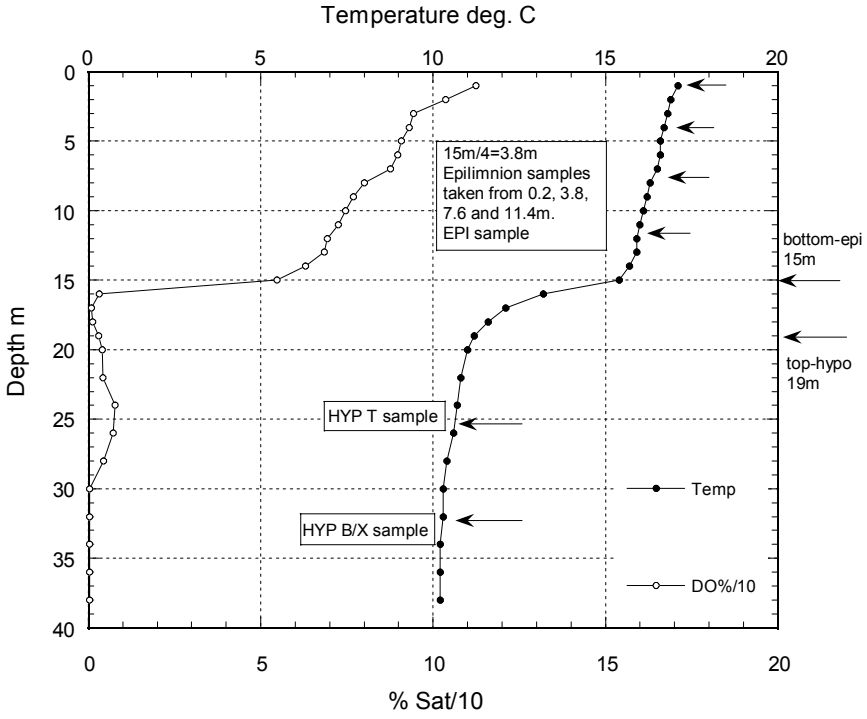


Figure 2.3 (b): Sampling depths for a lake in the stratified condition

Epilimnion sampling

The bottom-epi depth is not always easy to estimate, especially at the onset of stratification or when there are periods of temporary stratification during long periods of windless days. In-field selection of layer depths can differ from those chosen at the end of the stratified season (*see* section 4.2). For example, from the profile plots for Lake Tutira (Figure 4.1) the bottom-epi, field-selected depths can be estimated as: October, 5 m; November, 6 m; December, 4 m; January, 6 m; February, 3 m; March, 10 m; April, 14 m. These are relatively easy to choose, as the knee is distinct. The problem is to select an appropriate depth at the onset of stratification in September. Running a ruler down the profile will give a value ranging from 7 m to 9 m. Either value will enable a reasonable snapshot of the epilimnion to be achieved.

Once the bottom-epi depth is determined from the T/DO depth profile taken at a station, it is divided by four. Using this calculation, the epilimnion is sampled at depths of 0.2 m and one-quarter, one-half and three-quarters of the epilimnion thickness and the samples pooled in a 20-litre container. This sample is then well mixed and subsampled into a rinsed 1-litre container and a rinsed 5-litre container.

The sample is labelled with the lake name, site code, date and the code "EPI". This will keep the sample from becoming confused with the sample from the hypolimnion. (The intermediate layer – the thermocline – is not sampled.)

Hypolimnion sampling

The lowest layer is the hypolimnion. A sample should be taken from the middle of this layer if it contains oxygen at all depths. Again, using the plots of Lake Tutira in Figure 4.1, the in-field selection of the top-hypo depths would be: September, 14 m; October, 16 m; November, 14 m; December, 15 m; January, 17 m; February, 18 m; March 17 m; April, 21 m. These are not the same as the top-hypo depths shown in the figure, which were selected at the end of the stratified season as the *seasonal top-hypo depths*.

A sample is taken at the mid-depth between the top of the hypolimnion and the lake bottom. A 1-litre subsample is taken for nutrient analysis. The sample bottle is rinsed with a little water from the Van Dorn bottle before the sample is taken. This sample is labelled with the lake name, date and the code "HYP". However, if there is a deoxygenated zone (less than 3% sat DO) in the hypolimnion, two hypolimnion samples are needed. The first is taken at one-third depth from the top of the hypolimnion and the lake bottom, and, again, labelled with the lake name, site code, date and the code "HYP". The second sample is taken in the middle of the anoxic zone and labelled with the lake name, site code, date and the code "HYP-B/X". This prevents the two samples from becoming confused with each other and with the samples taken from the epilimnion above. The two samples are not to be mixed.

All the above samples must be stored in chilly bins with ice as soon as they are taken. A major effect of anoxia is the dramatic increase in the release rate of nutrients such as ammonia and soluble reactive phosphate, as well as iron, manganese and other minerals from the sediments. The occurrence of high concentrations of these compounds in anoxic waters is often a truer indication of anoxic conditions than an oxygen probe measurement of, say, 5% saturation, because the reliability of probes decreases near the zero DO concentration point.

Van Dorn sampling procedure

Once the decisions have been made about whether the lakes are isothermal or stratified and the sampling depths have been calculated, the water samples can be taken. The Van Dorn sampler is opened and the trigger mechanism is set, keeping fingers clear of the sampler edge in the event that there is a misfire. The sampler is lowered vertically to the required depth on a marked line. The messenger unit or weight is attached to the line and released. The weight drops and hits the trigger mechanism so that the rubber doors of the Van Dorn close and the sample is taken at the desired depth. The Van Dorn sampler is then brought back to the surface and the sample placed in the appropriate rinsed sample bottle.

2.7 Sample handling on return to base

Usually the samples collected during a day will be handed over to the laboratory for processing on return to base. If the field team members cannot return to base on the same day, they should courier samples to the laboratory on the day of collection. However, because of possible deterioration, the Chla sample should be filtered on the day of collection and the frozen filters delivered by the field team on return to base.

Filtering of the chlorophyll a *sample*

The 5-litre sample is first mixed thoroughly to ensure all algae are resuspended. The 100 ml phytoplankton sample is taken first. This is placed in a 120-ml sample container labelled with the lake, site code and date and 1 ml of Lugol's solution is added to preserve the sample. The lid of the sample bottle can be taped to ensure that it stays on, especially if the samples are to be transported to another destination. The remainder of the sample provides the Chla sample.

The Chla sample should be filtered and frozen as soon as possible after collection because even samples that are chilled and stored in the dark may show higher levels of Chla than those filtered in

the field straight after collection. Two duplicate samples are filtered for each site. The sample is shaken to resuspend the algae and the appropriate amount of sample is poured into a measuring flask.

The filtering equipment consists of two chambers that screw together. The connection between the two chambers holds a Whatman GF/C filter. The bottom chamber is connected to a vacuum pump for drawing the water through the filter paper. The vacuum pump is turned on and the sample poured into the top chamber of the filtering equipment. The measuring flask is rinsed with distilled water which is then poured into the top chamber. When all the sample has been filtered, the top chamber is also well rinsed with distilled water, using a squirt bottle to ensure that all algae are washed down the sides of the chamber onto the filter paper. The vacuum from the filter pump should not exceed 250 mm (10 inches) of mercury or 35 kPa and total filtration time should not exceed 10 minutes. The pump is turned off before the filtering chambers are dismantled. Failure to do this first may result in the filter paper being torn apart. The filter paper is then folded over (plankton inside), placed in a labelled 120-ml container and immediately frozen. These samples need to be kept frozen at a temperature below -16^{o}C. If they are to be transported to another laboratory for analysis, they can be transported in a chilly bin with dry ice (available from most gas suppliers).

Dispatch of samples to the laboratory

The nutrient samples are repacked in ice and placed in a labelled chilly bin as soon as possible after returning to shore. These are handed over or couriered to the laboratory as soon as possible after return from the lake.

2.8 Maintenance of equipment between samplings

Correct long-term care of equipment enhances its lifetime and efficiency of use. All equipment should have permanent storage places in between sampling trips, preferably in the same area. The following items need special maintenance:

- DO meter
- DO probe
- Van Dorn sampler
- Secchi disc
- boat and towing vehicle

DO meter

It is recommended that the batteries be replaced at least once a year. This could be done during the first month of each year. At this time, the small packet of silica gel should be redried and placed back in the meter. It will also be time to check the seal joining the two halves of the meter case. If moisture has been getting inside the meter, new seals should be purchased. Internal moisture – the biggest enemy of DO meters – causes corrosion in the selector switch, which leads to erratic readings and eventually to failure of the meter. Switch replacement is expensive: not only the switch but also the electronic board has to be replaced. Often it may be better to replace the whole meter.

DO probe

The DO probe must always be stored in a moist environment and not be allowed to dry out. The KCL solution for the probe is half water and half salt. When stored in an environment of less than 100% saturation of air with water vapour, the water contained in the probe will evaporate, concentrating the KCl solution. Crystals then form inside the probe and may damage it. A wet sponge wrapped around the probe and placed in a sealable plastic bag permits storage of the probe for long periods. Storage of the probe directly in water can encourage algal growth, which can affect the quality of the measurements. Probe membranes or glands wear out: they become stretched, cut and fouled with use, reducing the oxygen exchange rate and the quality of the readings. Membrane replacement frequency will vary, depending on use, and may be as short as every two weeks or as long as every three months.

Experience will dictate the frequency of replacement as gland changes occur, ideally before a sharp fall in quality of readings is noted. The probe should be totally replaced every two to three years. Fall-off in quality of output is rapid, so if the probe is changed before it breaks down, lost data can be kept to a minimum. When the probe is attached to the cable it is recommended that the o–ring connector seal be coated with silicon grease.

Van Dorn sampler

The Van Dorn sampler will need a visual examination of the rubber connector only. When storing it, put a paper handy towel in the rubber jaws of the sampler to prevent them sticking as the sampler dries out. By keeping the jaws open, the inside of the sampler also has a chance to dry out. If the Van Dorn sampler is starting to give trouble by not closing when triggered, it is useful to strip the firing mechanism down, clean it in white spirits, lightly lubricate it with silicon grease and then reassemble. If this is done every few months, the sampler should give trouble free-service. Before stripping it down, mark the position of the spring adjuster fitting so that it can be assembled in exactly the same position. The rope on the Van Dorn sampler, particularly where the messenger hits the Van Dorn trigger mechanism, has to be inspected regularly as it tends to wear excessively at this point. If the rope breaks, the sampler is lost.

Secchi disc

A quick visual inspection of the disc for chips or flaking paint is all that is required. The disc should be touched up as necessary. Always store it dry to prevent the formation of rust.

Boat and Towing vehicle

Any maintenance noted during a sampling run will need to be carried out before the next sampling run. Common-sense boat care makes the job easier.

A quick visual check is all that is required for all remaining equipment. Any faults noted in the field need attention before the next sampling run. It is important that all equipment is dry before it is stored.

2.9 Knowledge necessary for good performance

A knowledge of quality assurance will be important in producing good repeatable results. Technical staff must always be quality focused and well organised. It is important to constantly check and evaluate performance. The project leader should explain the results and findings of each year's work to the field and laboratory staff to enhance their understanding, performance and level of observation.

Lakes are complex environments and their sampling requires knowledge and good judgement. Rules and guidelines for sampling can never cover all eventualities, so it is important that field staff have some understanding of lakes. Recommended reading on limnology includes *The Algal Bowl* (Vallentyne, 1974) and *Lake Manager's Handbook* (Vant, 1987).

The project leader should accompany the field staff or replace a member of the field team on one sampling trip on each monitored lake each year. This helps the project leader to understand what is being asked of the field team in the different sampling routines, and allows in-field checking and instruction of the field team on optimal techniques. Moreover, a first-hand knowledge often improves the project leader's understanding of the monitored lake.

Chapter 3. Laboratory analysis of samples

Topics of sample handling are discussed in the initial sections of this chapter, followed by the detailed methods for analysing the different variables in the later sections. Determinands (and their abbreviations) may be grouped according to their method of quantification (physical measurement, chemical analysis or calculation):

Measurement by meter

- hydrogen or hydroxyl ion activity (pH)
- electrical conductivity (EC)
- turbidity (Turb)

Filtrate analysis

- chlorophyll a (Chla)
- total suspended solids (TSS)
- inorganic suspended solids (ISS)

Nutrient analysis

- dissolved reactive phosphorus (DRP)
- total phosphorus (TP)
- ammoniacal nitrogen (NH3-N)
- nitrate nitrogen (NO3-N)
- total nitrogen (TN)

Calculation by subtraction

- organic suspended solids (OSS) = {TSS – ISS}
- phosphorus difference (Pdiff) = {TP – DRP}
- total organic nitrogen (TON) = {TN – (NO3-N + NH3-N)}.

3.1 Sample processing for immediate or delayed analysis

Determinands are separated into those that need immediate processing upon receipt of samples and those for which analysis can be delayed. pH, Chla filtrations, and sample division and filtration for total and dissolved nutrients are of primary interest. Turbidity and conductivity are of optional interest, though these can be useful for characterising the nature of the sample before carrying out nutrient analyses; for example, high turbidity signals possible high TP and TN content. High conductivity (increased salinity) signals possible problems for certain automated dissolved nutrient analyses. Conductivity is also useful to distinguish the source of a sample if a mix-up, either in the field or in the laboratory, is suspected. The following analyses are carried out when convenient after initial processing of the samples: DRP, NH3-N, NO3-N; TP; TN; TSS; ISS; Chla.

Samples come into the laboratory from the lake in two bottles per sample. There should be a 1-litre sample bottle, which has been collected primarily for pH, EC, Turb and nutrient analyses and another 2-litre bottle collected for Chla, TSS and ISS analyses. The samples should also be accompanied by a

field sheet giving details of the date, station and depth (or depth range) from which they were collected. This information should be recorded against each laboratory sample identification number.

The 1-litre sample bottle should first be warmed to room temperature (if previously kept on ice) and then moved to mobilise any sediments and create a homogeneous solution. The pH can be measured at this stage by inserting the pH electrode directly into the opened container. It is imperative that the pH electrode has been thoroughly rinsed with purified water to remove traces of buffer solution, electrolyte etc which could contaminate the sample.

Re-cap and shake the sample in the 1-litre bottle to mix all sediments well, then pour an appropriate quantity (approximately 100 ml) into a sub-container labelled for TP and TN analysis, and a similar volume into another sub-container destined for optional conductivity and turbidity measurements. Leave the bottle for a short while for "heavy" sediments to settle out. Aliquots of the supernatant sample can then be used for filtration for analysis of dissolved nutrients (DRP, NH3-N, NO3-N). If nutrients are not to be analysed immediately, the sub-containers for both total and dissolved nutrients should be stored frozen until analysis.

For analysis of dissolved nutrients, the sample undergoes filtration through a membrane filter of 0.45-µ pore size (together with a glass fibre GF/C pre-filter if necessary). The most convenient filter diameter is 47 mm. Filtration devices may be positive pressure (using a syringe and a screw-together filter holder) or negative pressure (using a filter holder/reservoir and vacuum flask apparatus). 100 ml of filtered sample should be sufficient. Use of an aseptic technique is most important to avoid any inadvertent contamination of the sample during the filtration process. Filters should have several separate aliquots of purified water passed through them before passage of each sample. If samples are relatively clean (free of sediments) filter assemblies may be used to process several samples before the filters are renewed. Occasional blanks (purified water instead of sample) should be included. Blanks should comprise three sub-containers – one with unfiltered purified water, another with purified water that has been passed through a fresh (pre-rinsed) membrane-GF/C filter assembly, and a third with purified water passed through a filter assembly that has already had sample passed through it. This latter step provides a check on whether there is any significant release of nutrients that may be stripped (under the conditions of the filtration process) from solids retained on the filter.

For Chla and SS analysis, samples are filtered through 47-mm GF/C filters. The filters (plus any retained residue) are kept for subsequent analysis. Use sample from the 2-litre field container, employing the filter holder/reservoir and vacuum pump apparatus. Filter appropriate volumes of sample for both tests (this can range from 100 ml to 1 litre each, depending on the sediment load present). Although suspended solids filtration does not have to be carried out immediately, Chla filtration does. Chla filters should be folded, placed in a small plastic or tinfoil wrap and stored frozen until time of analysis.

3.2 Quality checks on data

A quality control regime should be implemented in association with all the test procedures carried out. APHA (1998: pp 1-4, Part 1020, Quality Assurance) gives a good outline of the type of requirements to be considered.

Internal method checks

For the nutrient analyses, it is specially important to cross-check that working calibration standards are made up correctly on each occasion. One way is to prepare independent analytical quality control (AQC) check solutions. This comprises combined intermediate AQC solutions (made from independent stock solutions to that used for the calibration standards) that contain desired ratios of phosphorus, nitrate and ammonia from which working check solutions can be readily prepared on the day of the analysis run.

Data evaluation checks

Data should be put into a spreadsheet as soon as at hand (both field- and laboratory-generated). Results should initially be in chronological order as samples are collected and put through the

laboratory system chronologically. Periodically this data can be copied and pasted into another spreadsheet for sorting according to site, date, location and depth parameters. A visual scan can then be made of other grouped parameters to look for possible outliers. Where such are detected, certain remedial actions may need to be carried out, such as the re-analysis of the sample.

- Outliers, or suspect results, may arise because of the following circumstances:
- The field sample container has become contaminated, either before, during or after collection of the sample.
- The field sampler apparatus, such as the depth pump, was contaminated.
- The laboratory filtration apparatus or sample sub-containers were contaminated, or some aspect of sample handling at this stage has caused the contamination.
- The sample became contaminated during storage or during the analysis procedure.
- The analytical procedure was faulty (either for individual samples, partial or whole batch): for example, inconsistent sample or reagent addition volumes; incorrectly prepared standards or reagents; sample interferences.
- Samples were inadvertently mixed up with other samples at some stage; for example, put into wrongly labelled containers.
- Instrument readings were recorded incorrectly (this includes field measurements, such as DO and temperature), or instruments were incorrectly calibrated or improperly set up.
- Calculations associated with the various types of sample analyses were in error.
- Data transcription from field sheets or laboratory analysis sheets into the spreadsheet were recorded incorrectly.
- The result is, in fact, true, but difficult to otherwise confirm.

Some anomalies (such as switched samples) can be resolved, whereas others (such as field sample container contamination) can not. Re-analysing a sample for an anomalous dissolved nutrient result should be done on both the filtered and unfiltered sub-containers. It is possible that the former was contaminated but not the latter. The laboratory manager should try to determine whether the suspect values are the result of contamination or procedural errors. If no cause for anomalous values can be found, a decision may have to be made as to whether a particular outlier is removed from the database. This should be done only by the project leader.

After one year from the start of the project, a more rigorous approach to data scrutiny should be applied. Annual averages and their standard deviation for each parameter per site should be obtained by the project leader and the findings discussed with the laboratory manager. Thereafter, updated values should be obtained on a more frequent basis, such as monthly, in order to identify possible outliers more quickly.

3.3 Sample storage before and after analysis

Sample containers should be filled completely in the field with sample to leave no air space. The containers should then be placed in crushed ice in a chilly bin for transit back to the laboratory. Laboratory processing should be carried out within 24 hours of sample collection. Sample fractions destined for later analysis should be stored frozen (in sub-containers). After analysis, these samples should be quickly refrozen and kept until results have been checked for anomalies that might require re-analysis. Storing frozen samples indefinitely presents problems of space availability, so it is important for quality checks be made on the data on a regular basis, allowing samples that have been satisfactorily analysed to be discarded.

3.4 Long-term maintenance of analytical quality

The objective of the programme of monitoring lakes is to detect change, so it is important that the laboratory analytical capability remains consistent even over the long term – possibly over 20 years. This is best done by the laboratory maintaining a rigorous quality control programme, which is checked by an outside agency, such as International Accreditation of New Zealand (IANZ).

However, some regional councils do not maintain their own laboratories and contract out their chemical analyses. This is not a problem if councils retain the services of a particular laboratory with a strict quality control programme. The problem arises when the analyses are put out to tender in order to keep the cost as low as possible. Different laboratories may then be chosen from time to time to carry out the lake sample analyses. Inter-laboratory analysis checks have shown consistent variation in results between different laboratories, even when all are of high standard. Change of laboratory, or of a methodology in the same laboratory, can mask slight changes occurring in the short term in the samples from lake monitoring – this is a very serious consideration.

If analytical methods in a laboratory are changed or if the contracted laboratory is changed, there should be a period of duplicate analyses using both the old and new methods or laboratories. When sufficient analyses have been done, conversion factors between the old and the new methods or laboratories can be generated and applied to the old data for the different variables. This procedure is not foolproof, and the optimum situation is to have all analyses done by the same high-quality laboratory.

3.5 Phytoplankton procedures

Samples for estimation of phytoplankton abundance and taxonomic identification (species identification) should be collected in duplicate. One sample should be preserved immediately, preferably with Lugol's iodine solution. A second live sample should be kept for examination within 24 hours of collection if the capability exists for prompt analysis of phytoplankton samples. Live specimens should be kept in darkness at 2–6^{o}C (Etheridge, 1985). Taxonomic identification should be made on live material where possible, as preservation can cause problems for identification including the distortions of shape and the loss of flagella. However, for many groups, such as diatoms, preservation has no detrimental effects – indeed, special preservation techniques can enhance the identification process.

Direct microscopic examination is required for taxonomic identification and for the estimation of phytoplankton abundance (as numbers) and biomass (as cell volume). Phytoplankton should be viewed with a microscope at 100–400x magnification; smaller phytoplankton cells sometimes require magnification up to 1000x for identification. The microscope should contain an eyepiece graticule (calibrated with a stage micrometer) for the cellular measurements. At least 10 individuals of a particular species should be viewed and measured before identification is confirmed. Identification will require a range of references, depending on the sample. The level and degree of taxonomic identification will always be dictated by the availability of references and the skill level of the biologist. Useful references for New Zealand lakes include Prescott (1962), Pridmore and Hewitt (1982), Cassie (1984), Pridmore and Etheridge (1987) and Jolly (1959).

For quantification of standing crop, individuals are counted from a known volume. The most common method used for this procedure is the Utermohl-sedimentation technique (Lind, 1974) where phytoplankton preserved in Lugol's iodine solution are allowed to settle in a special counting chamber. The counting chamber is placed directly on the stage of an inverted microscope where the cells settled from the added known volume can be counted. Counting 100 random distributed cells will produce an accuracy of ± 20%; counting 400 random distributed cells will produce an accuracy of ± 10%. It is recommended that a minimum of 300 cells – preferably, more than 400 cells – are counted.

Phytoplankton size is highly variable (up to 1,000-fold), for this reason, data derived on a volume per volume basis (μm^3 ml^{-1}) is often more meaningful than data given in numbers of cells per millilitre.

Again, live material will often give a more actuate estimate of biomass, and a minimum of 10 individuals per species should be counted. Spines, projections and gelatinous envelopes should not be included in measurements. For phytoplankton of a readily definable shape (such as a sphere, cone or cylinder), volume can readily be calculated using simple geometric approximations. For more complex structures computations should be based on a composite of shapes. The cell volume of each taxon should be computed and used to calculate a mean volume. This should be recalculated where possible for each sampling occasion as size can vary greatly between different environments (eg, lakes, depth). Total phytoplankton abundance can be estimated in terms of cell volume per millilitre by multiplying the mean cell volume by the number of cells.

3.6 Methods for chemical determinands

This section is a brief discussion on methods of quantitative analysis and choice of methods. The procedures are described in *Standard Methods for the Examination of Water and Wastewater* (APHA, 1998). Each laboratory should have a copy of this book. However, there are some modifications to the APHA methods that are recommended here because they are more suited to the concentrations found in New Zealand lake waters. The first determinands described (pH, conductivity and turbidity) involve measurement by meter – the next (Chla and suspended solids), analysis of filtrates. These are followed by general recommendations on analysis of dissolved and total nutrients, then by detailed methodolgy relating to phosphorus and nitrogen in various forms.

pH

For measurement of pH, employ the method described in APHA (1998: pp 4–87, Part 4500, H+ B) in conjunction with the instrument manufacturer's instructions. The most important aspect is the efficacy of the pH electrode in terms of sensitivity, response time and longevity. For lake samples, which will predominantly be of low ionic strength, electrode performance should be checked out regularly against a natural water "buffer" solution of low ionic strength. This solution can be prepared by dissolving 0.084 g anhydrous sodium bicarbonate in 1 litre of purified water. A 100-ml portion of the solution is taken outdoors, poured several times between two clean 100-ml containers, then split between the containers, which are capped and shaken. Repeat pouring and shaking procedure five times, then recombine as one solution. The intention is to bring the solution into equilibrium with atmospheric carbon dioxide (the environment must be fresh air, away from vehicle fumes etc). At equilibrium, the expected pH is 8.24 at 20°C, and 8.28 at 25°C. Take another 50-ml portion of solution, breathe into it and shake. This will lower the pH to below 7.00. Place the electrode in this solution first and wait until the pH is below 7. Then place the electrode in the air-equilibrated solution. If the pH does not rise above 8.10, electrode sensitivity is suspect. Also, observe the time for the reading to stabilise. This should not take more than a few minutes. A specific recommendation is made here for the Radiometer GK2401C glass electrode which has proven performance characteristics with respect to measuring water of low ionic strength. For principal calibration, purchase commercially available standard pH buffers at pH 4, 7 and 10.

APHA (1998: pp 1-34, Part 1060 C, Sample Storage and Preservation) recommends that pH be determined immediately after taking the sample to avoid possible changes that might otherwise occur. Note, however, that pH measurements made in the field are difficult to perform accurately, so it is preferable that they are carried out under controlled laboratory conditions. To retard any changes in the sample while in transit, the sample container should be filled to the top to exclude all air and placed in ice in a chilly bin.

Electrical conductivity

Employ the method for EC measurement (APHA, 1998, pp 2-46, Part 2510 B) in conjunction with the instrument manufacturer's instructions. Accuracy should be checked regularly against potassium chloride (KCl) conductivity standards, which cover the anticipated response range of the samples. This should include regular checks on purified water and the water used for preparation of the KCl standards (this should register less than 1 $\mu S\ cm^{-1}$).

Turbidity

Employ the method for measurement of Turb (APHA, 1998, pp 2-9, Part 2130 B) in conjunction with the instrument manufacturer's instructions. Note that instruments of different make and model may vary in response to the same sample.

Chlorophyll *a*

The method for Chla analysis (APHA, 1998, pp 10-18, Part 10200 H) is used without modification. As practicable, filtrations (and subsequent analysis) should be carried out in duplicate as a quality assurance measure.

Total suspended solids

Because of the low concentrations of suspended solids usually encountered in lake samples, TSS analysis (APHA, 1998, pp 2-57, Part 2540 D) should be carried out in duplicate – or triplicate if possible – as a quality assurance measure. The aluminium dishes used to hold the filter papers should be made of foil rather than of solid construction in order to minimise the difference in weight between the filter (plus retained solids) and the dish.

Inorganic and organic suspended solids

This protocol recommends analysis of ISS (and OSS by subtraction) in terms of fixed and volatile solids ignited at 400°C. Note that the APHA method (1998: pp 2-58, Part 2540 E) specifies ignition at 550°C. This temperature is considered too severe for the examination of freshwater lake samples where solids concentrations are usually low; also, some variability in the test may occur because of possible weight losses from the aluminium holding dish. The lesser temperature of 400°C for a minimum of 6 hours (overnight) is preferred and allows for better stability, as may be confirmed by replicate blanks and samples.

Dissolved and total nutrients: general recommendations

This section describes methods for soluble nutrient analysis referenced to *Standard Methods for the Examination of Water and Wastewate*r (APHA, 1998); in addition, section 3.7 gives details of the autoanalyser method for soluble nutrient analysis developed and adopted by the NIWA Hamilton Analytical Laboratory (further details of this method, which has been found to be very satisfactory, are available upon request from the Laboratory Manager, NIWA Hamilton, PO Box 11-115, Hamilton, New Zealand). Both manual and automated colorimetric methods are available for DRP, NH3-N and NO3-N. The TP and TN tests require an initial digestion step, followed, respectively, by DRP and NO3-N colorimetric finishes. However, the manual methods for soluble nutrients and the digestion procedures for total nutrients presented in APHA use sample volumes in the order of 25–50 ml. For the study of lake samples such volumes may be considered unnecessarily large, and are inconvenient for carrying out large numbers of analyses, notwithstanding inclusion of blanks, standards, quality control checks and replicate samples. Some rationalisation and streamlining has been applied to the methods.

Analyses by autoanalyser are preferred to manual analyses. An autoanalyser provides the analyst with:

- a better consistency (controlled conditions of analysis) achievable for each analysis batch
- the capacity to accommodate large numbers of samples more easily (including calibration standards, quality control checks, replicates etc)
- an increased confidence in values obtained near the limit of detection
- the ability to review a whole run in retrospect by examining the sample responses from the chart recorder or data capture system
- the capability of carrying out simultaneous analyses for DRP, NH3-N and NO3-N from the same sample vial in the sampler carousel

- the use of a combined standard solution for calibration purposes.

As well, the DRP and NO3-N lines can be used for the colorimetric finishes for the TP and TN tests respectively (regrettably, these cannot be combined simultaneously). Note that because of the unpredictability of the performance of the cadmium column reduction method for nitrate, the hydrazine reduction method for nitrate should be used in the first instance. The exception is where there is an obvious interference with the hydrazine method as may happen with salt water, saline waters and waters with high dissolved organic content.

The sample volume dispensed for TP, TN, and manual DRP, NH3-N and NO3-N tests should be standardised at 8.00 ml, accompanied by a proportional reduction in the volumes of reagents added. For sample delivery, use an appropriate hand-held dispenser which has been pre-calibrated (using purified water and a two-place balance) to deliver 8.00 ml (± 0.05 ml). Using a marker pen, carefully draw a line around the dispenser tip at the base of the meniscus to mark where the 8.00 ml limit is. Use this line as an observation point to check volume delivery consistency with every sample. Note also that variations in delivery volume can be caused by different sample temperatures. Ensure all samples, standards etc are at (or near) room temperature before dispensing. The same marked sample dispenser tip can be used for all sample deliveries, rather than a fresh tip each time. Due care is required to avoid possible cross-sample contamination – for example, flushing out the tip with purified water between sample deliveries.

For dispensing reagents, use appropriate reservoir pipettors that have been pre-calibrated (using purified water and a two-place balance) to accurately deliver the desired volumes. These should be checked periodically for delivery consistency (based on the established reagent delivery weight).

10-ml capacity, disposable, capped, plastic vials can be used as reaction vessels. They can be purchased in bulk at relatively cheap cost, along with compatible plastic test tube racks. All items should be of autoclavable quality (necessary for TP and TN tests). The vials can also be used directly, or be adapted for direct use, with autoanalyser sampler units. No extensive precleaning or pretreatment of the vials is required, though it is advisable to rinse with hot tap water, then purified water, just before use to remove possible atmospheric contamination such as from dust or ammonia. Note, however, that if the vials are used directly for holding sample in an autoanalyser carousel for DRP analysis, there may be some loss (adsorption) over time of sample P onto the internal plastic surfaces. Some initial experimentation (analysis of replicate samples, spread over several hours) should be carried out to determine whether a problem exists and, if so, the extent of the problem. There is no problem with the DRP colorimetric finish for the TP test.

Recommended analytical methods, based on APHA (1998), are summarised below for phosphorus and nitrogen in various forms:

- manual dissolved reactive phosphorus
- automated dissolved reactive phosphorus
- total phosphorus
- manual ammoniacal nitrogen
- automated ammoniacal nitrogen
- manual nitrate nitrogen
- automated nitrate nitrogen (cadmium reduction method)
- automated nitrate nitrogen (hydrazine reduction method)
- total nitrogen

Manual dissolved reactive phosphorus

For manual DRP (*see* APHA, 1998, pp 4-146, Part 4500-P E. Ascorbic Acid Method) it is recommended that 1.23 ml of colour reagent be added to 8.00 ml of sample. To maximise method

sensitivity, use a spectrophotometer set at 880 nm, and a cuvette with a 40-mm path length. This will allow resolution to 0.5 ppb P. If a cuvette or flow cell with a path length of 10 mm is used, then a resolution of only 2 ppb P is achievable. Arsenates are a major positive interference. If such interference is suspected, this can be minimised by a metabisulphite/thiosulphate reduction step before colour development. The analyst will need to adopt a two-step reagent addition scheme as developed and used by the NIWA Hamilton Analytical Laboratory. With this scheme, 1 ml of the reductant is added to 8 ml of sample, and mixed. Then 1 ml of colour reagent is added, and mixed. Because the reductant needs to be acidic for stability reasons, both reductant and colour reagent must be prepared with split acidity levels. (Section 3.7 describes the NIWA automated DRP method; the same reagents can be used for the manual test.) Silica can be a positive interference if present above 10 ppm SiO_2. The interference effect increases with time after addition of the colour reagents, so sample absorbances should be read on the spectrophotometer as soon as practicable after the minimum required colour development period.

Automated dissolved reactive phosphorus

Automated DRP analysis (*see* APHA, 1998, pp 4-148, Part 4500-P F. Automated Ascorbic Acid Reduction Method) employs the use of a commercially available autoanalyser and the same reagents as are used for the manual DRP test. Method sensitivity is maximised by using a 50-mm flow cell, 880-nm colorimeter filter and a sample analysis rate of 30 samples per hour (with 2:1 sample/wash ratio). The purified water line and mixing coil can be omitted, and the sample line delivery rate changed from 0.42 ml min^{-1} to 0.80 ml min^{-1} (red/red-coded pump tube). Set up the autoanalyser to operate in the range 0–50 ppb P. A resolution 0.5 ppb P should be achievable.

APHA has omitted to include a wetting agent in the combined colour reagent. It is recommended that Levor V (Technicon Instruments Corporation, product no. T01-1165) be used, five drops per 100 ml.

The same interference problems exist as described for the manual DRP test. If a reductant solution is required to minimise interference from arsenates, the autoanalyser manifold will need to be modified to incorporate addition of this reagent to the sample stream. It is suggested that the NIWA DRP method be adopted. For silicates, interference is minimised by virtue of the relatively short colour development time before absorbance measurement in the colorimeter. Note, also, that the temperature of the water bath should not be increased for any reason beyond the recommended 37°C, as this will enhance any silica interference effects.

Total phosphorus

The TP analysis method as written (APHA, 1998, pp 4-143, Part 4500-P B. Sample Preparation 5. Persulphate Digestion Method) involves several time-consuming steps for the digestion procedure (such as the addition of solid persulphate to each sample and neutralisation with sodium hydroxide after digestion). This can be streamlined if 1.00 ml of a prepared digestion reagent containing potassium persulphate is added to 8.00 ml of sample, and the neutralisation step bypassed by using a P colour reagent of reduced acidity.

The following instruction is for preparation of 100 ml of acidified potassium persulphate digestion reagent. (Prepare a greater quantity if necessary, based on the total number of samples, replicates, blanks, standards etc, plus at least 50 ml excess for filling the bottom of the reservoir dispenser and for priming the dispenser.) Weigh out 5.0 g potassium persulphate ($K_2S_2O_8$), and transfer to a 100-ml volumetric flask. Add 70 ml purified water and swirl the contents. Using a graduated pipette, slowly add 5.0 ml concentrated sulphuric acid (H_2SO_4) to the swirling solution. Make up to the 100-ml mark with purified water. Cap the flask, and mix by inverting until dissolution of the solid is essentially complete (this may take several minutes). A small quantity of solid residue may remain. Leave this behind when transferring the solution to the reagent dispenser. The reagent has proved to be stable for at least a week, even when it has been dispensed into vials containing sample. Endeavour to secure a supply of potassium persulphate guaranteed as low as possible in background P (and N).

Ensure that sample vials and caps are autoclavable and are indelibly marked with identification numbers (use a spirit-based marker pen). Samples with a suspected TP greater than 1000 ppb P should

be suitably diluted with purified water before analysis. Once samples have been dispensed and digestion reagent added, cap the tubes and mix the contents. Place in a pressure cooker or autoclave to operate at 15 psi (121°C) for 30 minutes. Allow tubes to cool, mix contents, then analyse for P employing either the manual or automated DRP method previously described. Turbidity in the digestate (usually arising from suspended solids in samples) may cause a positive interference. If using an automated colorimetric finish, leave the digested samples to stand overnight before proceeding with the analysis. The turbidity will have mostly settled out. If using a manual colorimetric finish, it may be necessary to run a duplicate set of samples through the digestion process with one sample being a correction blank.

Note: the P colour reagent must be made with half the usual strength of sulphuric acid solution to compensate for the sulphuric acid already present from the digestion reagent. With the APHA method, use 25 ml only of 5N sulphuric acid (rather than 50 ml) plus 25 ml purified water for each 100 ml of combined reagent prepared. For the NIWA method, use 2.5N sulphuric acid in place of the 5N sulphuric acid. Failure to observe this instruction will result in reduced or nil colour formation because of an incorrect pH level.

Additional operating notes. Prepare:

- phosphate calibration standards of 5, 10, 25, 50, 100, 200, 500, 750 and 1000 ppb P
- phosphate quality control check standards of 200 and 1000 ppb P
- digestion check standards, sodium hexametaphosphate and adenylic acid (adeonsine monophosphate), each at 200 and 1000 ppb P.

For autoanalyser use, include five or more vials of 200 and 1000 ppb P phosphate calibration standards to provide sufficient quantity for periodic standardisation checks within the autoanalyser run. Include 10 or more vials of purified water blanks to provide sufficient solution for dilution and colorimetric re-analysis of off-scale samples. For all other standards and check solutions, include at least duplicates. Take the mean response values of the duplicates to establish a calibration curve.

Set up the autoanalyser for operation either in the 0–200 ppb P or 0–1000 ppb P range, depending on where the majority of samples are expected to lie. If the former, with only a few off-scale samples, it is simpler to dilute these with digested blank solution and re-run, rather than setting up the 0–1000 ppb P range. If the latter, it will be necessary to reduce colorimeter sensitivity by using a 15-mm flow cell, and/or a colorimeter filter of lower wavelength. One option is to use the 540-nm filter from the nitrate colorimeter, which will allow analysis to proceed with the 50-mm flow cell still in place. Note that for the 0–1000 ppb P, range a non-linear standard curve may be produced.

Manual ammoniacal nitrogen

Instead of three separate reagents being added to the sample for manual NH3-N analysis (APHA, 1998, pp 4-108, Part 4500-NH3 F. Phenate Method), it is recommended that this be reduced to two reagents by combining the phenol and nitroprusside solutions at the time of preparation (though this cannot be stored beyond the day of use). Also, reagent addition can be set at 1.00 ml each to 8.00 ml of sample. If liquid phenol is not available, use solid phenol (10.0g to 100 ml final volume with ethyl alcohol). A resolution of 2–5 ppb N is achievable, but atmospheric ammonia contamination can be a problem.

Automated ammoniacal nitrogen

Automated analysis of NH3-N (APHA, 1998, pp 4-109, Part 4500-NH3 G. Automated Phenate Method) employs a commercially available autoanalyser and chemistry similar to that used for the manual ammonia test. Method sensitivity is maximised by using a 50-mm flow cell, 630-nm colorimeter filter, and a sample analysis rate of 30 samples per hour (with 2:1 sample/wash ratio). Set up the autoanalyser to operate in the range 0–100 ppb N. A resolution of 2 ppb N should be achievable, but atmospheric ammonia contamination can be a problem.

Additional operating notes: If liquid phenol is not available, use solid phenol. Dissolve 83.0 g solid phenol in 500 ml purified water before adding the NaOH.

In the APHA instructions, the water bath temperature is given as 50°C. However, if carrying out simultaneous automated analyses for DRP, NH3 and NO3, and employing a single communal water bath, a compromise temperature of 37°C is required.

Manual nitrate nitrogen

Nitrate ion at low concentration (low parts per billion) cannot be determined directly by colorimetry, so must first be converted to the more reactive nitrite ion for which the following methods are designed. What ultimately is measured in a sample is nitrate plus any nitrite originally present. The correct expression for results is therefore "nitrate + nitrite nitrogen". For lake waters, nitrite is usually assumed to be absent or minimally present. If required, a simple separate test for nitrite can be made. A manual method is available for detection of low-level nitrate, but it can be difficult to implement, erratic and not well suited for processing large numbers of samples. For this reason, the automated methods are considered the better option.

The analytical method for manual NO3-N as written (APHA, 1998, pp 4-117, Part 4500-NO3- E. Cadmium Reduction Method) is designed to cater for a wide range of sample sources, nitrate concentrations, and interferences. Together with the relatively large volume of sample/stabilising solution required to be passed through the column, the method is limited in the number of samples that can be processed in a given period. Sensitivity is also limited by the large volume of stabilising solution added to the sample.

To increase productivity the analyst could experiment as follows:

- Construct several shorter mini-columns that require less sample volume throughput per column (to handle, say, 20-ml aliquots, of which 8 ml is retained for final colour development).
- Use a 10x more concentrated ammonium chloride/EDTA stabilising solution so that less volume of this is added to a given volume of sample (thus increasing method sensitivity).

Additional operating notes pertaining to use of mini-columns:

- Use a top end standard of 100 ppb N only to ensure that linearity is maintained.
- Pass eluent through a second time if necessary to enhance reduction efficiency.
- Between samples, flush mini-columns with purified ammonium chloride/EDTA solution to remove possible carryover effects.

The essential criterion, however, is that the reduction efficiency of nitrate to nitrite is maintained at 85–100% in any one reduction tube. In terms of spectrophotometer absorbance relating to the final colour formation, this should approximate 0.300–0.360 absorbance units for the 100 ppb N standard (at 543-nm, 10-mm light path). For samples that exceed 0.360 absorbance units, these must be appropriately diluted and re-run. Minimum detection limit is 0.5 ppb N.

To check background nitrite-N, add 0.3 ml of colour reagent to 8 ml of fresh sample that has not been passed through the reductor column. Measure the absorbance and calculate nitrite concentration based on the relationship that 100 ppb N equates to 0.360 absorbance units (at 543-nm, 10-mm light path).

Automated nitrate nitrogen (cadmium reduction method)

This method of NO3-N analysis (APHA, 1998, pp 4-118, Part 4500-NO3- F. Automated Cadmium Reduction Method) employs the use of a commercially available autoanalyser and chemistry similar to that used for the manual nitrate test (an in-line cadmium reduction column). Method sensitivity is maximised by using a 50-mm flow cell and 540-nm colorimeter filter, and adopting a sample analysis rate of 30 samples per hour (with 2:1 sample/wash ratio). Set the autoanalyser to operate in the range of 0–100 ppb N. A resolution of 1 ppb N or better is achievable. To work in the 0–1000 ppb N range, a simple 1-in-10 dilution loop can be added to the manifold.

Note that for freshwater analyses, the automated hydrazine reduction method (*see below*) is preferred because the reduction efficiency of nitrate to nitrite is maintained at a consistent level indefinitely. With the cadmium reduction column, performance is unpredictable: the cadmium may lose its reducing power during the course of an analysis run or on stand-down between analysis runs. The cadmium column method is useful, though, when dealing with saline and seawater samples, or samples with high dissolved organic matter. These conditions cause dramatic interference problems with the hydrazine reduction method.

The APHA method as presented gives no information regarding the construction or insertion of the in-line cadmium column. According to an instruction from the Technicon Industrial Method no. 158-71W, the reductor column may comprise "a fourteen inch length of 0.081 inch ID standard tubing" (ie, plastic purple/purple-coded pump tube). To fill the tube with prepared cadmium granules, first plug one end and attach the other end to a cut-down 60-ml plastic syringe barrel to act as a convenient filling funnel. Suspend the arrangement from a retort stand and fill the tube with purified water. Then add the prepared cadmium granules, taking care to exclude any granules that may be oversize with respect to the tube diameter. It is important that air bubbles are not entrained in the tube during the filling operation or during subsequent handling. Remove the funnel and insert an appropriate connector unit into the top of the tube. Lift up the bottom of the tube, remove the end plug and join to the connector. This maintains a holding loop until the column is required on the autoanalyser. Alternatively, use a commercially available reductor column (coil form).

Start the autoanalyser pump working without the reductor column in place. Allow all transmission lines to be filled with solutions and cleared of air bubbles. Check that the A2 debubbler on the sample line is operating correctly – removing air bubbles and leaving a continuous (unbroken) sample stream. At this stage, connect one end of the reductor column to the A2 debubbler. Then join the other end to the resample line. Some prior preparation will be necessary to ensure that appropriately sized connector units are employed for ready connections to be made. To reactivate cadmium which has lost its reducing power, rinse the column through (using a connected syringe) with 1N hydrochloric acid, followed by purified water, then by copper sulphate solution.

Automated nitrate nitrogen (hydrazine reduction method)

The second method for automated NO3-N analysis (APHA, 1998, pp 4-119, Part 4500-NO3- H. Automated Hydrazine Reduction Method) also employs the use of a commercially available autoanalyser. The manifold configuration shown in APHA can be adjusted to cover a wide range of nitrate concentrations. For the examination of lake samples, it is proposed that two interchangeable ranges be standardised: 0–100 ppb N (where resolution of 1 ppb N is achievable) and 0–1000 ppb N (where resolution of 10 ppb or better is possible). The choice of range will depend on experience gained from various sample sources. The 0–1000 ppb N range is recommended for the colorimetric finish for the TN test. Response sensitivity should first be maximised by using a 50-mm flow cell, a 540-nm colorimeter filter, and adopting a sample analysis rate of 30 samples per hour (with 2:1 sample/wash ratio). The configuration shown in APHA has an approximately 1-in-9 built-in sample dilution loop. Together with the other measures to maximise sensitivity, this provides the conditions to set up the 0–1000 ppb N analysis range. To set up the 0–100 ppb N analysis range requires rearrangement of the dilution loop to put through more sample and less distilled water. It is suggested that the sample line be changed to 1.20 ml min^{-1} (code yellow/yellow) and the distilled water line to 0.05 ml min^{-1} (code orange/red). This effectively provides a fivefold increase in sensitivity with no significant change in combined volumes.

Total nitrogen

The method for TN analysis (APHA, 1998, pp 4-102, Part 4500-N C. Persulphate Method) comprises two stages: (a) digestion of the sample to convert nitrogenous compounds to nitrate; (b) a nitrate colorimetric finish. The first stage, as written, requires modification to streamline handling procedures and to maximise sensitivity in the 0–1000 ppb N range, which is more relevant to the examination of New Zealand lake waters. Also, because of the logistics involved in handling a large number of standards and quality control checks in addition to the samples, the manual colorimetric finish is not

recommended. The following instructions apply to an automated colorimetric finish. In particular, the automated hydrazine method is preferred.

Two recommendations are made which differ from the APHA method (NIWA experience in adopting these recommendations has shown no loss in digestion effectiveness):

- Include boric acid along with potassium persulphate and NaOH in the digestion reagent, rather than adding it at a later stage. (Reference: *Methods of Seawater Analysis*, Grasshoff et al, 1983, pp 164-168.)
- Use 1 ml of a concentrated digestion reagent, added to 8.0 ml of sample.

The following instruction is for preparation of 100 ml of concentrated alkaline persulphate/boric acid digestion reagent. (Prepare a greater quantity if necessary, based on the total number of samples, replicates, blanks, standards etc, plus at least 50 ml excess for filling the bottom of the reservoir dispenser and for priming the dispenser.) To 90 mls purified water in a 100-ml measuring cylinder add 1.5 g sodium hydroxide (NaOH), 5.0 g potassium persulphate ($K_2S_2O_8$) and 3.0 g boric acid (H_3BO_3). Stopper the cylinder and mix contents for several minutes. Add purified water to make a final volume of 100 ml, re-stopper and mix until dissolution is essentially complete. A small quantity of solid residue may remain. Leave this behind when transferring the solution to the reagent dispenser. The reagent has proved to be stable for at least a week, even when it has been dispensed into vials containing sample. Endeavour to secure a supply of potassium persulphate guaranteed as low as possible in background N (and P).

Ensure that sample vials and caps are autoclavable and are indelibly marked with identification numbers (use a spirit-based marker pen). Samples with a suspected TN greater than 1000 ppb N should be suitably diluted with purified water before analysis. Once standards and samples have been dispensed and digestion reagent added, cap the tubes and mix the contents. Place in a pressure cooker or autoclave to operate at 15 psi (121°C) for 30 minutes. Allow tubes to cool, mix contents, then analyse for N employing one of the prescribed automated nitrate methods. Turbidity in the digestate (usually arising from suspended solids in samples) may cause a positive interference. Leave the digested samples to stand overnight before proceeding with the analysis.

Additional operating notes. At a minimum, prepare the following:

- nitrate calibration standards of 100, 250, 500, 750 and 1000 ppb N
- urea quality control check solution, 1000 ppb N (to cross-check the 1000 ppb nitrate-N calibration standard)
- nicotinic acid or glutamic acid solution digestion check solution, 1000 ppb N (to test percentage N recovery).

In the digestion run, include five or more vials of 1000 ppb N nitrate calibration standards to provide sufficient quantity of standard for periodic standardisation checks within the autoanalyser run. Include 10 or more vials of purified water blanks to provide sufficient solution for post-dilution and colorimetric re-analysis of off-scale samples. For all other standards and check solutions, include at least duplicates. In the autoanalyser run, include duplicates of all standards, check solutions and blanks. Take the mean response values of the duplicates to establish a calibration curve. The analyst may need to decide on a case-by-case basis whether a linear or non-linear relationship is more applicable.

3.7 NIWA Hamilton soluble nutrients autoanalyser method

The autoanalyser technique developed by NIWA is a quantitative test for the simultaneous determination of dissolved reactive phosphorus, ammoniacal nitrogen and nitrate nitrogen in water (*see* Figure 3.1 for a schematic outline of the process).

Reagents

1 Sampler wash water. Use fresh deionised water.

Stock reagents for DRP

2 Sulphuric acid, 5N

Concentrated sulphuric acid, H_2SO_4	141 ml

Add slowly, with mixing, to 800 ml deionised water in a conical flask. Cool, and make up to 1 litre with deionised water in a measuring cylinder.

3 Ammonium molybdate stock

Ammonium molybdate, $(NH_4)_6Mo_7O_{24}.4H_2O$	3.0 g

Dissolve in 100 ml deionised water. Stable for three weeks at 4°C.

4 Potassium antimony tartrate stock

Potassium antimony tartrate, $K(SbO)C_4H_4O_6.^1/_2H_2O$	0.14 g

Dissolve in 100 ml deionised water. Stable for two weeks a 4°C.

5 Sodium thiosulphate stock (2% solution)

Sodium thiosulphate, $Na_2S_2O_3$	2.0 g

Dissolve in 100 ml deionised water. Stable for three weeks at 4°C.

6 Sodium metabisulphite stock (20% solution)

Sodium metabisulphite, $Na_2S_2O_8$	20.0 g

Dissolve in 50–80 ml deionised water and make up to 100 ml final volume. Stable for five days at 4°C.

Working DRP reagent solutions

7 Reductant (50 ml = sufficient for 8 hours' operation)

Sodium thiosulphate stock, 2% solution	20 ml
Sodium metabisulphite, 20% solution	20 ml
Sulphuric acid, 5N	10 ml
Levor V (wetting agent)	1 drop

Prepare daily in a fume cupboard, using a 50-ml stoppered measuring cylinder. Mix gently by inversion. Occasionally remove the stopper to release evolved gas. *Caution*: fumes are unpleasant and toxic. Always prepare in a fume cupboard.

8 Mixed colour reagent (50 ml = sufficient for 8 hours' operation)

Sulphuric Acid, 5N	25 ml
Ammonium molybdate stock solution	10 ml
Potassium antimony tartrate stock solution	10 ml

L-ascorbic acid $C_6H_8O_6$	0.55 g
Deionised water	5.0 ml
Levor V (wetting agent)	3 drops

Prepare daily, using a 50-ml stoppered measuring cylinder. Add components in the above order. Stopper, and mix after each addition by inversion. Make up to 50 ml final volume with deionised water. *Important notes:*

- Use Levor V only for DRP reagents. Do not use for ammonia or nitrate reagents. Conversely, do not use Brij-35 for DRP reagents. Cross-use of these agents will cause massive interference problems.
- DRP reagents use 5N H_2SO_4. TP reagents use 2.5N H_2SO_4 to compensate for the acid already present in the digestion reagent. Incorrect acidity levels will result in reduced or nil colour development.

Reagents for NH3-N

9 Complexing reagent

Potassium sodium tartrate, $KNaC_4H_4O_6.4H_2O$	66.0 g
Sodium Citrate, $HOC(COONa)(CH_2COONa)_2.2H_2O$	48.0 g
Sulphuric Acid, H_2SO_4, concentrate	approximately 4.4 ml
Brij-35 (wetting agent) (NB: Do not use Levor V)	1.0 ml

Dissolve the potassium sodium tartrate and sodium citrate in 1900 ml deionised water in a beaker. Adjust the pH of this solution (using a calibrated pH meter) to 5.0 pH units with concentrated. sulphuric acid (approximately 4.4 ml). Make up to a final volume of 2000 ml with deionised water using a measuring cylinder. Add 1.0 ml Brij-35. Stable at room temperature for at least one month.

10 Alkaline phenol (two components)

Phenol, C_6H_5OH	83.0 g
Sodium Hydroxide, NaOH	37.0 g

Dissolve the phenol in approximately 400 ml deionised water. Dissolve the sodium hydroxide separately in approximately 400 ml deionised water. Mix and make up to a final volume of 1000 ml in a measuring cylinder. Stable for one month. *Important note:* Do not add solid phenol directly to sodium hydroxide solution. This may create unstable compounds that will result in an erratic autoanalyser baseline and reduced peak responses. Phenol must be hydrated first in deionised water.

11 Sodium hypochlorite solution

Janola (commercial bleach solution)	400 ml

Dilute 400 ml Janola to 1000 ml in a measuring cylinder. Stable for one week.

12 Sodium nitroprusside solution

Sodium nitroprusside, $Na_2Fe(CN)_5NO.2H_2O$	0.5 g

Dissolve in 900 ml deionised water in a 1-litre volumetric flask, and make up to the mark. Stable for one week.

Reagents for NO3-N

13 Diluent (for use with high range manifold)

Deionised water

Brij-35 (wetting agent) (NB: Do not use Levor V)

To approximately 2000 ml deionised water in a 2000-ml Erlenmeyer flask, add 1 ml Brij-35 solution and mix.

14 Catalyst solution

Cupric sulphate, $CuSO_4.5H_2O$	0.035 g
Zinc Sulphate, $ZnSO_4.7H_2O$	0.90 g
Brij-35 (wetting agent) (NB: Do not use Levor V)	0.5 ml

Dissolve the chemicals in deionised water in a 1000-ml volumetric flask, and make up to the mark. Add Brij-35 and mix thoroughly. Stable for one month.

15 Sodium hydroxide solution, 1M

Sodium hydroxide, NaOH	40 g

Dissolve in approximately 600 ml deionised water and make up to 1000 ml final volume in a volumetric flask with deionised water. Stable indefinitely.

16 Hydrazine sulphate solution

Hydrazine sulphate, $NH_2.NH_2.H_2SO_4$	1.71 g

Dissolve in deionised water in a 1000-ml volumetric flask and make up to the mark. Stable for several weeks at 4°C.

17 Sulphanilamide solution (10%)

Sulphanilamide, $NH_2C_6H_4SO_2NH_2$	10.0 g
Concentrated hydrochloric acid, HCl	100 ml

Add 100 ml concentrated HCl to approximately 600 ml deionised water and mix. Add the sulphanilamide and mix to dissolve. Make up to 1 litre with deionised water in a measuring cylinder, and mix. Stable for several months.

18 NEDDE Solution (0.1%)

N-(1-naphthyl)-ethylenediamine dihydrochloride (R grade)	0.50 g

Dissolve NEDDE in 500 ml deionised water. Store the solution in a dark bottle, at 4°C. Stable for one month.

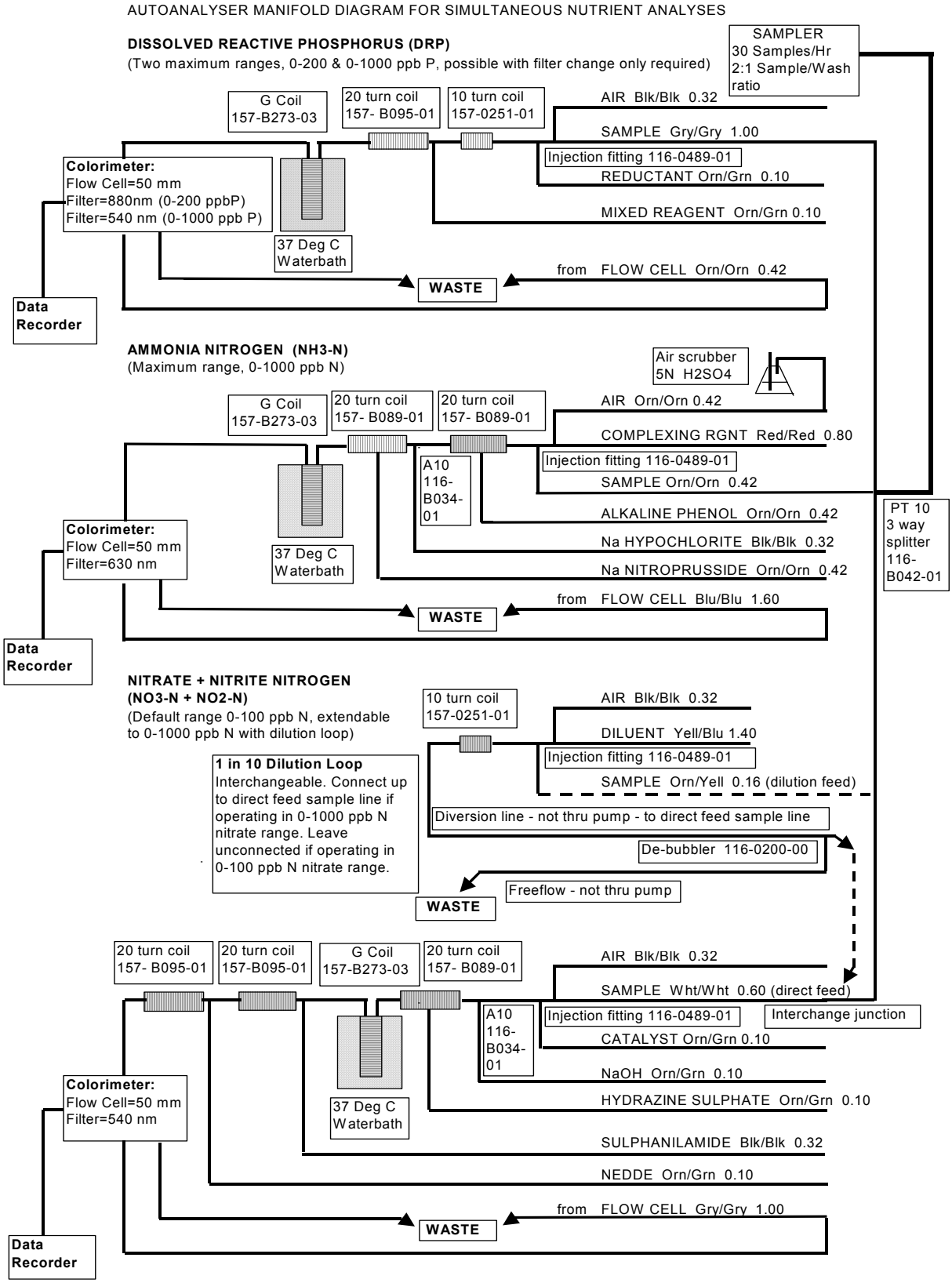


Figure 3.1: Schematic diagram of the autoanalyser setup for the simultaneous analysis of DRP, NH_3-N and NO_3-N + NO_2-N

Chapter 4. Management and surveillance of data

4.1 Data surveillance

The value of the results achieved in a lake monitoring programme depends initially on the quality of the data. The project leader must accept responsibility for the data that is archived. To ensure that all parts of the monitoring programme are well executed, the project leader should:

- accompany the sampling team at least once a year and watch all procedures on the lake
- ensure that the boat is being situated on station properly
- ensure that the field measurements, such as temperature and DO concentration profiles, as well as SD values, are being accurately taken
- discuss selection of the depths defining layers in the lake (*see* section 4.2) with the field team while on station
- check sampling and filtration procedures
- feel confident of the quality of the results produced by the laboratory receiving the samples
- ensure that the laboratory has the capability to reanalyse samples, if suspect results are obtained.

Because the behaviour of lakes can vary markedly from year to year, the field sheets generated on a sampling trip should be forwarded to the project leader soon after each trip for checking the current behaviour of the monitored lake. The project leader can watch for field data that seems out of range (and take remedial action if necessary) and check that the bottom-epilimnion and top-hypolimnion layer depths are being reasonably well chosen by the field team, with subsequent good selection of sampling depths.

One of the most important data surveillance tasks is the examination and acceptance of the analytical results from the chemistry laboratory. If the monitoring programme has commenced recently, there should be reasonable agreement between the values from the two sampling stations on a lake. If the programme has been running for some time and average values with their standard deviation are available for the different parameters for each month, these values provide guidance as to which results are acceptable which are suspect. Reruns of any suspect results should be done by the laboratory. The project leader should ensure that all field and laboratory data are entered correctly into the lake monitoring data archive file and calculate monthly averages with standard deviations for all parameters for the laboratory manager's guidance, as well as keeping a copy for reference. An example of a monthly average calculation sheet is shown in Table 4.1.

4.2 Selection of layer depths

The correct identification of the thermal layers present in the lake is an important matter, both in the field and subsequently in the data analysis phase. The monitoring procedures recommended in this protocol could be entitled "Limnology by Layers" because of the emphasis on identification of the different layers in a lake and on averaging values only from samples within the same layer. During the stratified season epilimnion values can differ markedly from hypolimnion ones, and it is meaningless to average numbers that are very different from each other when trying to find small trends in data. Thus the water column is divided into its layers when it is stratified, and the times when the lake is isothermal are clearly identified. Human contact with lakes is normally with the surface waters, so changes in the upper mixed layer (the epilimnion when the lake is stratified; the full water column when it is isothermal) are carefully observed. In the hypolimnion the most indicative variable is the HVOD rate and that is carefully followed for change during the stratified period.

Table 4.1: A partial table showing monthly average and standard deviation values for some variables for Lake Okareka

Site	Date	Chla (mg m^{-3})	Secchi (m)	TP (mg m^{-3})	TN (mg m^{-3})	DRP (mg P m^{-3})	NH4 (mg N m^{-3})	NO3 (mg N m^{-3})	pH	EC (µS cm^{-1})	Turb (ftu)
ROKC	4 Jan 93	0.8	10.78	4.0	170.0	0.0	9.0	1.0	8.28	77.3	0.39
ROKC	5 Jan 94	1.7	7.80	6.1		1.0	60.0	0.0	8.44	79.5	0.42
ROKC	7 Jan 95	1.2	9.93	6.0	176.1	0.0	4.0	1.0	8.21	79.4	0.71
ROKC	7 Jan 96	1.7	10.38	5.0	159.0	1.0	0.0	1.0	8.04	76.4	0.37
ROKN	4 Jan 93	1.1	12.05	4.0	180.0	1.0	8.0	1.0	8.34	77.3	0.38
ROKN	5 Jan 94	0.8	8.15	6.1		1.0	22.0	0.0	8.48	80.0	0.44
ROKN	7 Jan 95	1.2	9.43	6.0	191.0	0.0	3.0	1.0	8.11	78.7	0.40
ROKN	7 Jan 96	1.5	9.65	3.2	167.0	1.0	0.0	0.0	7.98	85.7	0.35
Averages		1.3	9.77	5.1	173.9	0.6	13.3	0.6	8.24	79.3	0.43
Std dev		0.4	1.38	1.2	11.1	0.5	20.2	0.5	0.18	2.9	0.12
ROKC	1 Feb 93	1.4	11.30	5.0	165.0	1.0	9.0	1.0	8.27	78.3	0.36
ROKC	19 Feb 94	1.7	11.05	6.8		1.0	40.0	2.0	8.57	78.7	0.61
ROKC	6 Feb 95	2.4	6.13	4.9	204.1	1.0	5.0	1.0	8.83	78.4	2.10
ROKC	11 Feb 96	2.7	8.63	5.0	160.0	0.0	3.0	0.0	8.17	76.5	0.37
ROKN	1 Feb 92	2.0	7.88	4.0	200.0	1.0	5.0	1.0	8.92	79.0	0.47
ROKN	1 Feb 93	0.8	11.35	5.0	185.0	1.0	8.0	1.0	8.08	78.0	0.43
ROKN	6 Feb 94	1.3	10.00	5.0		1.0	11.0	2.0	8.21	79.5	0.88
ROKN	6 Feb 95	3.3	6.43	4.9	206.8	1.0	4.0	1.0	8.78	78.4	1.40
ROKN	11 Feb 96	2.0	8.73	5.0	158.0	1.0	3.0	1.0	8.15	77.6	0.30
ROKS	1 Feb 92	2.1	7.18	7.0	275.0	1.0	4.0	1.0	8.93	78.4	0.62
Averages		2.0	8.87	5.3	194.2	0.9	9.2	1.1	8.49	78.3	0.8
Std dev		0.7	2.0	0.9	38.2	0.3	11.2	0.6	0.3	0.8	0.6
ROKC	28 Feb 93	1.4	10.75	4.0	170.0	1.0	6.0	1.0	8.44	79.0	0.35
ROKC	7 Mar 94	2.4	10.30	5.4		1.0		1.0	8.50	79.4	0.53
ROKC	7 Mar 95	3.8	6.18	3.0	151.3	1.0	5.0	1.0	8.95	79.3	0.46
ROKC	3 Mar 96	2.4	8.23	9.0	194.0	1.9	0.8	0.6	8.11	72.6	0.49
ROKN	1 Mar 92	2.5	6.67	7.0	195.0	1.0	3.0	1.0	8.55	79.9	0.63
ROKN	29 Mar 92	1.9	7.65	4.0	195.0	1.0	7.0	3.0	7.90	81.7	0.48
ROKN	28 Feb 93	1.5	10.80	2.0	175.0	1.0	7.0	1.0	8.42	78.5	0.38
ROKN	7 Mar 94	2.4	10.30	3.6		1.0	40.0	1.0	8.57	80.0	0.44
ROKN	7 Mar 95	3.6	6.33	5.0	199.8	1.0	5.0	1.0	8.91	79.1	0.54
ROKN	3 Mar 96	1.6	7.63	7.0	264.0	1.0	1.4	1.4	8.03	73.8	0.43
ROKS	1 Mar 92	4.1	6.72	7.0	220.0	0.0	4.0	1.0	8.64	79.7	0.52
ROKS	29 Mar 92	2.2	7.62	4.0	215.0	1.0	7.0	3.0	7.98	80.6	0.46
Averages		2.5	8.27	5.1	197.9	1.0	7.8	1.3	8.42	78.6	0.5
Std dev		0.9	1.8	2.0	31.0	0.4	10.9	0.8	0.3	2.7	0.1
ROKC	5 Apr 93	2.9	11.10	8.0	200.0	0.0	3.0	1.0	8.09	79.1	0.36
ROKC	5 Apr 94	2.5	10.65	6.1		0.0	19.0	0.0	8.05	78.5	0.54
ROKC	4 Apr 95	4.4	6.18	10.0	207.0	2.0	4.0	2.0	8.17	78.3	0.52
ROKC	7 Apr 96	2.7	8.03	7.0	182.0	1.0	4.0	1.0	7.82	76.1	0.47
ROKN	5 Apr 93	2.6	11.20	8.0	175.0	0.0	5.0	1.0	8.17	80.1	0.36
ROKN	5 Apr 94	2.7	10.45	7.9		1.0	16.0	1.0	7.53	78.8	0.43
ROKN	4 Apr 95	4.7	6.23	10.0	230.4	1.0	4.0	1.0	8.07	77.1	0.46
ROKN	7 Apr 96	2.4	8.16	7.0	174.0	1.0	4.0	0.0	7.83	74.3	0.43
Averages		3.1	9.00	8.0	194.7	0.8	7.4	0.9	7.97	77.8	0.4
Std dev		0.9	2.1	1.4	22.0	0.7	6.3	0.6	0.2	1.9	0.1
ROKC	2 May 93	2.4	10.50	7.0	195.0	0.0	4.0	2.0	7.88	80.1	0.29
ROKC	1 May 94	2.3	10.10	7.1		0.0	50.0	2.0	7.57	79.0	0.38
ROKC	6 May 95	3.6	6.28	10.0	173.5	1.0	4.0	1.0	7.56	77.6	0.47
ROKC	5 May 96	3.0	8.48	6.0	189.0	3.0	69.0	3.0	7.69	71.2	0.34
ROKN	3 May 92	2.2	9.51	4.0	150.0	1.0	2.0	1.0	7.71	80.4	0.35
ROKN	2 May 93	2.1	10.35	6.0	240.0	1.0	4.0	2.0	7.93	82.2	0.38
ROKN	1 May 94		10.45	7.1		0.0	55.0	2.0	7.75	79.2	0.37
ROKN	6 May 95	6.0	5.78	14.0	181.1	1.0	6.0	4.0	7.58	77.5	0.45
ROKN	5 May 96	4.0	8.63	5.0	193.0	3.0	13.0	2.0	7.67	69.0	0.47
ROKS	3 May 92	2.4	9.40	4.0	145.0	1.0	4.0	3.0	7.66	81.7	0.39
Averages		3.1	8.95	7.0	183.3	1.1	21.1	2.2	7.70	77.8	0.4
Std dev		1.3	1.7	3.0	29.7	1.1	26.0	0.9	0.1	4.4	0.1

Thermal structures vary considerably from lake to lake and even within one lake during a stratified season. Also, the epilimnion waters usually mix vertically to a greater degree than those of the hypolimnion. For these reasons, it is difficult to give well defined rules for selecting the layer breakpoints of the bottom of the epilimnion (or top of the thermocline) and top of the hypolimnion (or bottom of the thermocline). Figure 4.1 illustrates the selection and use of the layer depths.

Epilimnion waters are usually well mixed, so the bottom of the epilimnion depth (bottom-epi) is chosen as close as possible to the probable fully mixed depth during the period from a few days before to a few days after sampling. Hypolimnion waters do not mix vertically to a great extent, and since lake monitoring is trying to obtain both an accurate and a stable HVOD rate over a season, the top of the hypolimnion depth (top-hypo) is selected to give the thickest hypolimnion layer that is stable from the onset of stratification to the time when a DO concentration of 2 g m^{-3} is reached. Bottom-epi and top-hypo depths are selected on the lake by the sampling team so that they can chose their epilimnion and hypolimnion sampling depths; however, these depths are not always appropriate for the calculation of the seasonal hypolimnion average temperatures and DO concentrations. Selection of such depths is best done at the end of the stratified season when all the depth profiles are available and the pattern of thermal behaviour of the lake during the whole stratified season can be seen. Figure 4.1 shows plots for eight months of the 1995-96 stratified season in Lake Tutira. The bottom-epi depths can vary during the season and are chosen to be close to the thickness of the upper mixed layer.

The epilimnion sampling depths selected in the field were at 1.0 m and 9.3 m on 25 September 1995 so the bottom-epi depth was chosen at 10 m to fit in with these depths. The top-hypo depths were chosen to be constant at 15 m during the period when HVOD calculations were possible, from 25 September 1995 to 14 March 1996. This enabled the HVOD rate to be calculated for the same body of water during the stratified period. The data from the profile for 17 April 1996 could not be used for HVOD calculations because the average hypolimnetic DO concentration was below 2 g m^{-3} at that time. Also, there had been noticeable downward movement of the thermocline from March to April and this process usually causes significant reoxygenation of the hypolimnion waters. The occurrence of strong downward mixing and reoxygenation invalidates calculation of HVOD rates during the period of its occurrence (Burns, 1995).

4.3 Data storage and processing

The Excel (Microsoft Corp) spreadsheet program has been used to store the NZLMP data. The Kaleidagraph (Synergy Software) program was used for data manipulation and plotting results and the Data Desk (Data Description Inc) program for calculation of statistical results which are shown in Burns and Rutherford (1998). This procedure of switching between computer programs achieved the desired results but was tedious and time consuming. (Also, it worked because Burns had 30 years of experience in research limnology at the time, and was careful to modify the data processing methods when unexpected limnological situations were revealed by the data, as often occurred.) Subsequent discussions with data processing specialists revealed that the systems used to analyse the lakes monitoring data could be considerably improved. A program designed to work from data stored in a database format, instead of a spreadsheet format, permits easy and flexible numerical, statistical and plotting functions to be carried out and can deliver the required outputs in appropriate formats. Such a program, LakeWatch, has been developed by Knowlysis Ltd (Knowlysis, 1998). This program can display all the profiles from a lake for a stratified season simultaneously in different colours, making it easy to select the optimum top-hypo depth for the season.

4.4 Building the basic data files for a lake

The data management process has two parts: firstly, compiling the data from different sources into the basic data file; secondly; calculating the monitoring results from the basic data file. The remainder of this chapter is concerned with the first stage; the second process is explained in chapter 5.

The flowchart shown in Figure 4.2 illustrates the data processing sequence when using the Excel, Kaleidagraph and Data Desk programs.

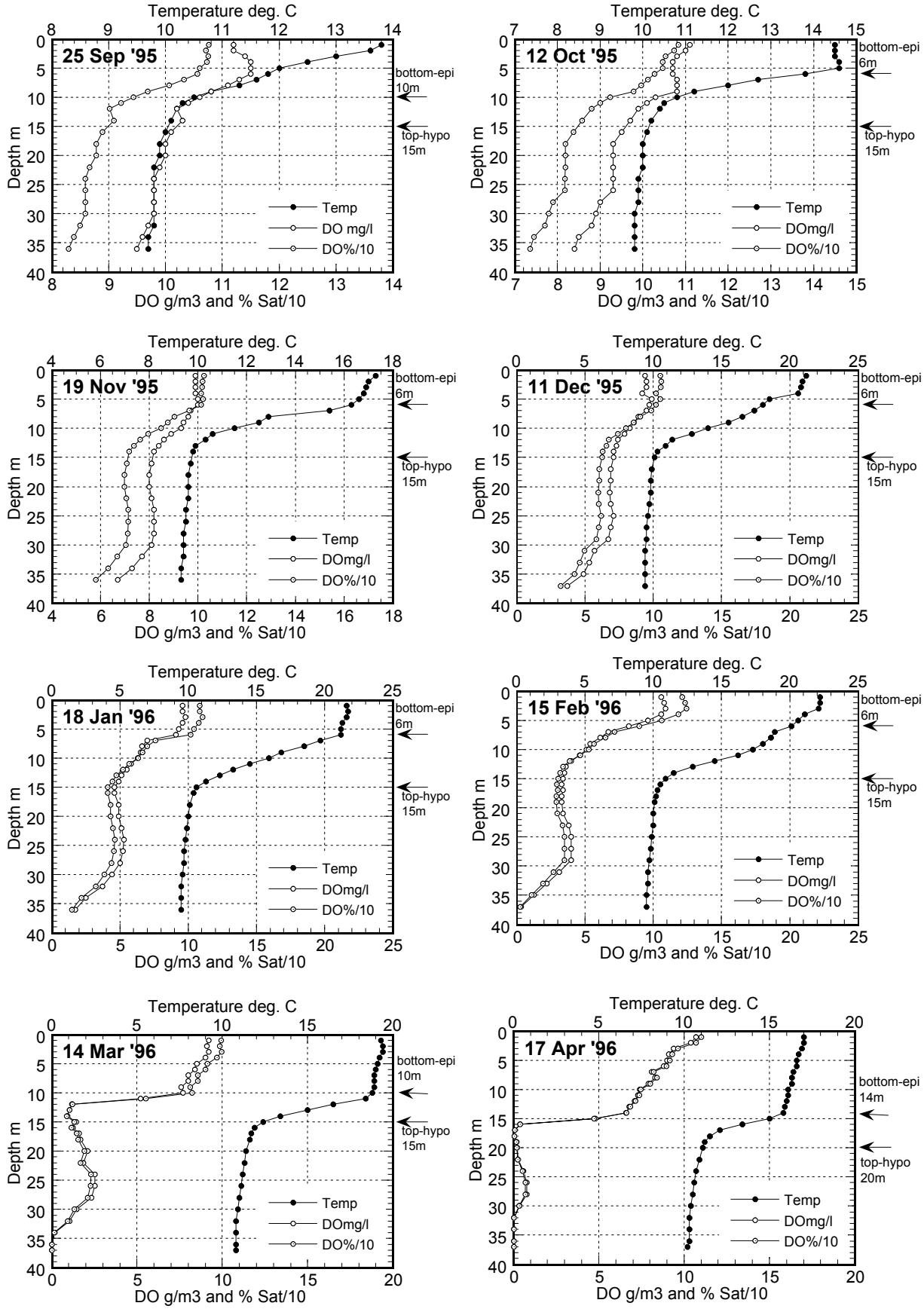


Figure 4.1: Profile plots for Lake Tutira for the 1995–96 stratified season, showing depths selected for the bottom of the epilimnion and top of the hypolimnion

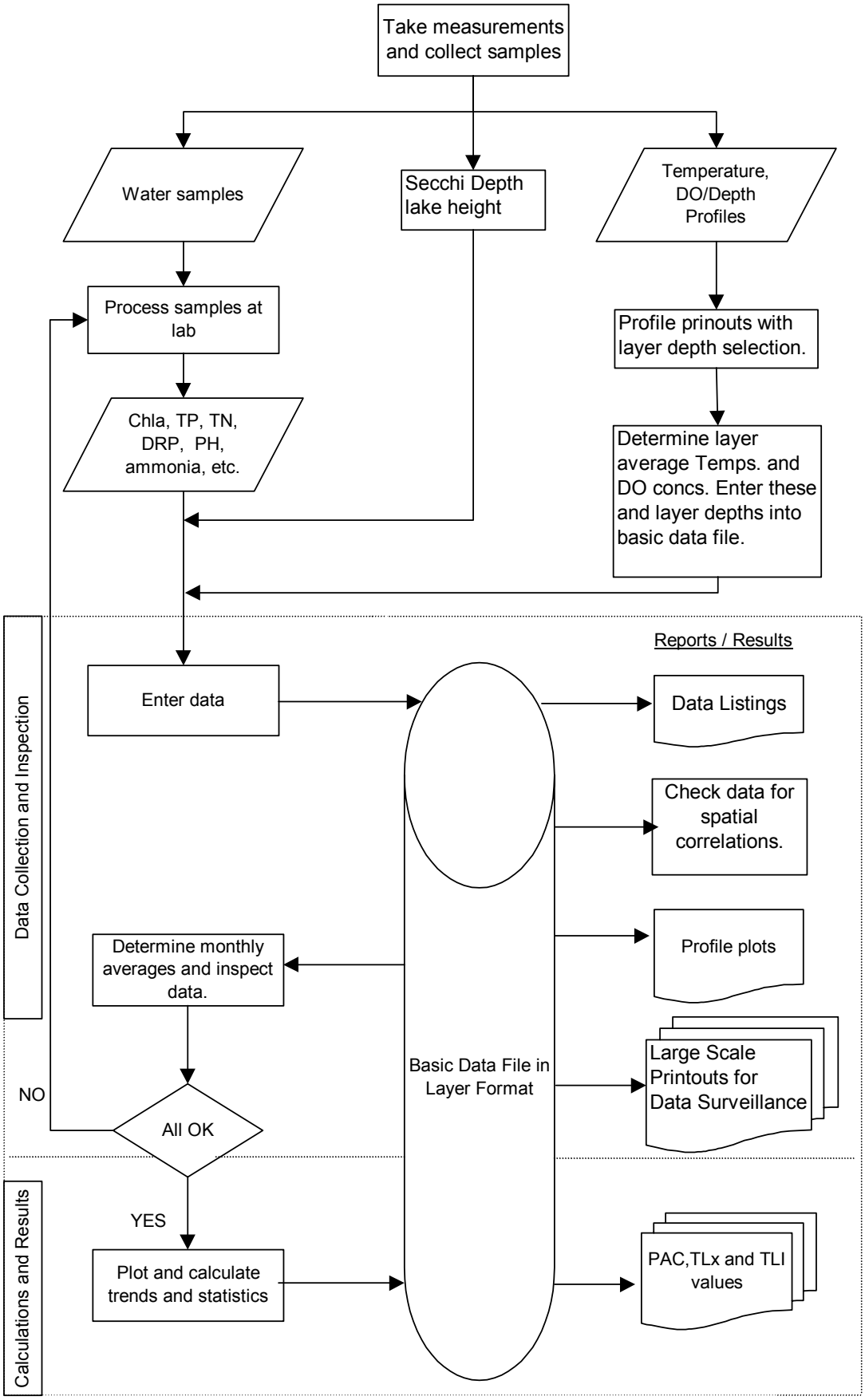


Figure 4.2: A flowchart showing the steps in preparing data and calculating results using the Excel, Kaleidagraph and Data Desk programs

The field data comes in on the field data sheets, illustrated in Figures 2.1 and 2.2. Profile data (a sample of which is shown below in Table 4.3) does not have any DO concentrations listed in it. They are calculated from equation (7) below.

$$DO\ (g\ m^{-3}) = (14.60 - 0.4027T + 0.007899T^2 - 0.00007722T^3) \times (\%\ sat/100) \times AF \qquad equation\ (7)$$

Where T = temperature (^oC)

AF = altitude factor.

Table 4.2 is a listing of altitude factors for different altitudes. The data for the derivation of this equation and the altitude factors was obtained from *Instruction Manual for the YSI Model 58 Dissolved Oxygen Meter* (YSI, 1981).

The data from the profiles data file (Table 4.3) is plotted out and the bottom-epi and top-hypo depths are chosen to define the thicknesses of the different layers. This is done at the end of the stratification season and a completed profiles data file then looks like Table 4.4.

The samples from the lake are handed in to the laboratory and entered into their sample identification sheets for analysis as described in chapter 3. When analysis of a batch of samples is complete, the data sheets are sent to the project leader. Data for the various variables are checked against their monthly average values to determine whether any samples should be rerun. Finally, layer average values from the profiles data file are combined with the field and laboratory data to obtain the basic data file in layer format as shown in Table 4.5.

Table 4.2: Altitude factors for calculating DO concentrations

Pressure (kPa)	Altitude (m)	Altitude factor	Pressure (kPa)	Altitude (m)	Altitude factor
101.3	0	1.00	84.1	1544	0.83
100.3	85	0.99	83.1	1643	0.82
99.3	170	0.98	82.1	1743	0.81
98.3	256	0.97	81.1	1843	0.80
97.3	343	0.96	80.0	1945	0.79
96.3	431	0.95	79.0	2047	0.78
95.2	519	0.94	78.0	2151	0.77
94.2	608	0.93	77.0	2256	0.76
93.2	698	0.92	76.0	2362	0.75
92.2	789	0.91	75.0	2469	0.74
91.2	880	0.90	74.0	2577	0.73
90.2	972	0.89	73.0	2689	0.72
89.2	1066	0.88	71.9	2797	0.71
88.2	1160	0.87	70.9	2909	0.70
87.1	1254	0.86	69.9	3023	0.69
86.1	1350	0.85	68.9	3137	0.68
85.1	1447	0.84	67.9	3253	0.67

Note: The altitude factor is used in equation (7).

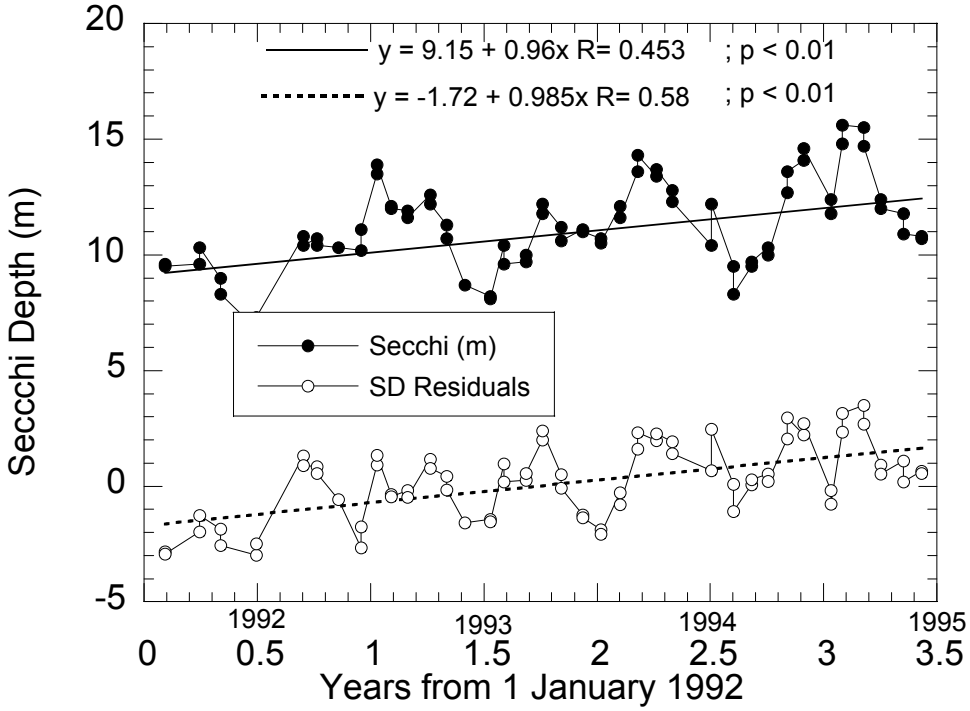


Figure 4.3 (a): Sample of a large-scale printout of data from Lake Okataina from 1992 to 1995

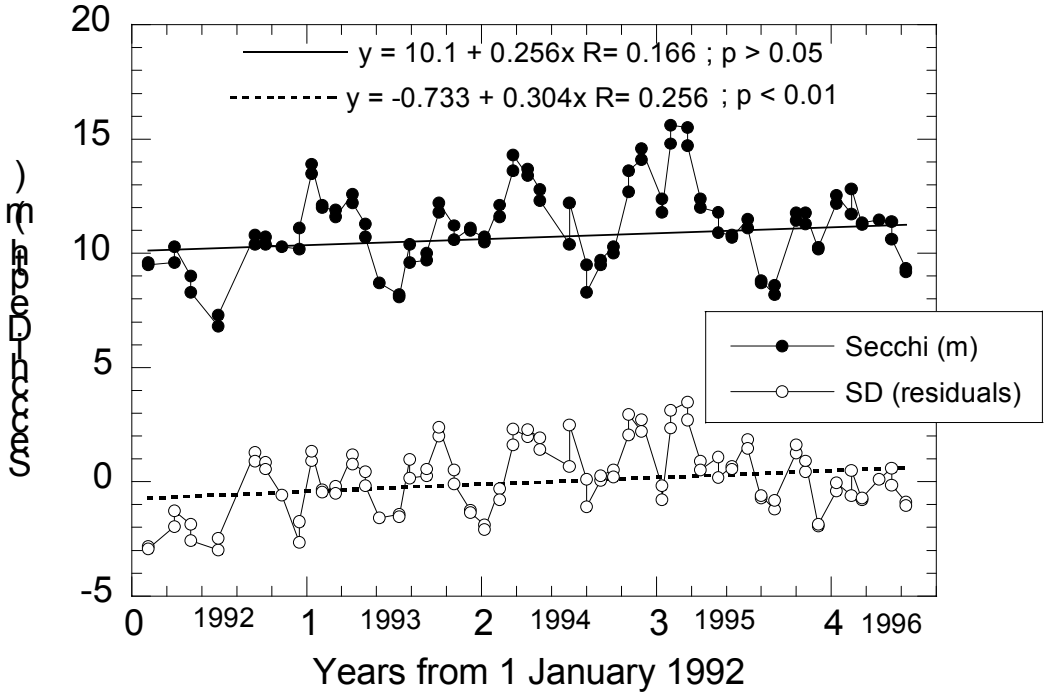


Figure 4.3 (b): Sample of a large-scale printout of data from Lake Okataina from 1992 to 1996 showing the lower values observed after September 1995

4.5 Data and results storage

The data is kept in the files described above, but an essential part of monitoring data surveillance is to print out results of the monitoring once a year, just after the limnological year is complete. (In August almost all New Zealand lakes are isothermal, so the limnological year is taken from 1 September to 31 August.) Comparison of one year's results with another is easier with hard copy printout than on a computer screen. Examples of such printouts are shown in Figure 4.3 (a) with data to June 1995 and Figure 4.3 (b) with data to August 1996. These comparisons are important in the data surveillance process to check for consistency in the data and results, and to find the cause of change when consistency is lost.

Reports on the monitoring of lakes are not usually generated each year; indeed, formal reports with the results of monitoring might be generated only every fifth year or so. The author of these reports, who is probably the lake-monitoring project leader, highlights important findings or trends found since the previous report and presents significant results in a space-saving format. This is appropriate for most readers, but the project leader should also examine the results each year in large-scale format, to observe changes of patterns in the data as soon as possible. This surveillance procedure helps to ensure that any unusual results during the past year are noted and, if caused by an error, that action is taken to rectify the matter. If no mistakes have been made, the annual inspection of results alerts the project leader to findings from the monitoring programme while it is ongoing, allowing possible changes to the sampling pattern.

Once the computer files are well organised and up to date as described in the previous sections, hard copies of the results should be produced and placed in a ring binder. One binder per lake is usually adequate if it is divided into sections for the different types of results. Each binder should have a pocket attached to the inner front cover containing a chart of the lake with sampling positions marked on it.

The first section of a ring binder for a lake should have the printouts of the profiles data and plots of the profiles that were used for the selection of the layer depths. If the lake is stratified, the next section should contain the plots of the average hypolimnetic temperatures and DO concentrations against days after 1 September, with the HVOD and temperature increase rates calculated for the most recent stratified season, as shown in Figure 5.6.

The third section should contain a printout of the updated monthly averages and annual averages for all variables. The final section should contain the latest printout of the annualised data for each of the four key variables of Chla, SD, TP and TN. The printout with the previous years' data can be thrown away if there is little change. Each of these variables should also have a full-page printout of their time trend plots of observed data and deseasonalised residuals from the start of monitoring to the present time, with the latest data included. Examples of this type of plot are shown in Figure 4.3. Its development is described in detail in section 5.2. These large-scale plots are important because they make it easier to see trends and changes in trends.

If a good file of annual results on a lake is maintained, it will make development of a monitoring report relatively quick and straightforward, as well as ensuring the quality of the data while it is being obtained and recorded. A second ring binder should be kept on each lake to contain all the field sheets completed during the on-lake sampling.

Table 4.3: Sample of a depth profile from Lake Hayes as observed

Station	Date	Depth m	Temp ¡C	DO % sat
AXHN	5 Oct 93	0.5	9.9	108.7
		2	9.9	109.1
		4	9.8	109.3
		6	9.8	109.4
		8	9.5	108.4
		10	8.8	106.2
		11	8.6	104.5
		12	8.3	102.7
		13	8.1	101.7
		14	7.7	99.5
		15	7.6	98.6
		16	7.4	97.4
		17	7.3	97.3
		18	7.3	96.9
		20	7.2	96.6
		22	7.1	92
		24	7	88.4
		26	6.9	89.4
		28	6.9	90.6
		30	6.9	83.6
		31.5	6.9	69.7

Table 4.4: Sample of depth profile data from Lake Hayes after determination of the layer change depths and average layer temperatures and DO concentrations

Station	Date	Depth m	Temp ¡C	DO % sat	DO g m^{-3}	DO % sat/10	Layer	Layer depths, thickness (m)	Layer av temp (¡C)	Layer av DO (%)	Layer av DO (mg $litre^{-1}$)
AXHN	5 Oct 93	0.5	9.9	108.7	12.38	10.87					
		2	9.9	109.1	12.42	10.91	Bottom-epi	10 m			
		4	9.8	109.3	12.47	10.93	Top-hypo	20 m			
		6	9.8	109.4	12.49	10.94					
		8	9.5	108.4	12.46	10.84	Epilimnion	10	9.62	108.51	12.44
		10	8.8	106.2	12.41	10.62	Thermocline	10	7.83	100.14	11.98
		11	8.6	104.5	12.27	10.45	Hypolimnion	11.5	6.99	87.19	10.65
		12	8.3	102.7	12.15	10.27					
		13	8.1	101.7	12.09	10.17					
		14	7.7	99.5	11.94	9.95					
		15	7.6	98.6	11.87	9.86					
		16	7.4	97.4	11.78	9.74					
		17	7.3	97.3	11.8	9.73					
		18	7.3	96.9	11.75	9.69					
		20	7.2	96.6	11.74	9.66					
		22	7.1	92	11.21	9.2					
		24	7	88.4	10.8	8.84					
		26	6.9	89.4	10.94	8.94					
		28	6.9	90.6	11.09	9.06					
		30	6.9	83.6	10.24	8.36					
		31.5	6.9	69.7	8.53	6.97					

Table 4.5 (a): Sample of final data file in layer format showing epilimnion data only

Site ID	Date	Lake height	Sampling depths	Layer code	Av layer temp (¡C)	Av layer DO %	Av layer DO (mg/l)	Station depth	pH	EC (µS/cm)	Turb (FTU)	Secchi depth	DRP ppb P	NH4 ppb N	NO3 ppb N	TP ppb P	TN ppb N	TON ppb N	Pdiff ppb P	Chla ppb
Epi or isothermal		(m)	(m)					(m)				(m)								
AXHN	4 Mar 92	-0.001	0.25-7.4	1	15.5	97.7	9.81	33	8.98	156	1.5	3.22	0	5	2	11	335	328	11	8.3
AXHS	4 Mar 92	-0.001	0.25-7.1	1	15.4	96.7	9.7	30	9.01	156	1.4	3.1	1	6	1	9	345	338	8	8.4
AXHN	7 Apr 92	0.081	0.25-5.4	1	12.4	93.7	10.07	31.8	8.86	162	2.7	2.35	7	40	2	30	410	368	23	23.1
AXHS	7 Apr 92	0.081	0.25-4.8	1	12.5	99.7	10.7	29.5	8.94	166	2.9	2.1	0	7	2	28	365	356	28	26.2
AXHN	5 May 92	0.077	0.25-8.4	1	10.8	89.1	9.92	31.7	8.39	165	1.7	3.65	8	39	9	33	425	377	25	15
AXHS	5 May 92	0.077	0.25-10.4	1	10.9	89.2	9.9	29	8.37	164	1.5	4.5	9	55	9	29	355	291	20	11.8
AXHN	9 Jun 92	0.051	7.9	1 Iso	7.5	78.9	9.5	31.8	7.81	166	0.68	3.7	48	170	24	61	430	236	13	8.1
AXHN	9 Jun 92	0.051	23.7	1 Iso	7.5	78.9	9.5	31.8	7.76	167	0.61	3.7	50	190	22	64	450	238	14	
AXHS	9 Jun 92	0.051	7.3	1 Iso	7.5	77.8	9.4	29	7.81	166	0.83	3.5	46	155	24	59	425	246	13	8.7
AXHS	9 Jun 92	0.051	21.8	1 Iso	7.5	77.8	9.4	29	7.75	166	0.71	3.5	48	190	22	63	410	198	15	
AXHN	4 Aug 92	0.241	8	1 Iso	4.5	99.7	13	32.2	8.29	166	1.5	3.15	26	105	40	57	395	250	31	21.9
AXHN	4 Aug 92	0.241	24	1 Iso	4.5	99.7	13	32.2	8.28	166	1.5	3.15	27	105	46	59	390	239	32	
AXHS	4 Aug 92	0.241	7.5	1 Iso	4.4	98.6	12.8	30	8.21	166	1.1	2.78	26	105	48	59	380	227	33	23
AXHS	4 Aug 92	0.241	22.5	1 Iso	4.4	98.6	12.8	30	8.23	166	1.3	2.78	29	100	48	59	390	242	30	
AXHN	6 Oct 92	0.201	8	1 Iso	6.6	95.8	11.81	32	8.23	166	0.67	3.2	22	18	95	38	385	272	16	4.8
AXHN	6 Oct 92	0.201	24	1 Iso	6.6	95.8	11.81	32	7.85	164	0.67	3.2	31	67	100	44	415	248	13	
AXHS	6 Oct 92	0.201	7.5	1 Iso	6.8	96.7	11.85	30	8.3	163	2.1	3.09	21	12	100	44	390	278	23	5.5
AXHN	10 Nov 92	0.241	0.25-6.5	1	14.1	121.3	12.55	32	9.09	160	1.2	2.83	1	9	0	30	350	341	29	6
AXHS	10 Nov 92	0.241	0.25-7.2	1	14	121.1	12.54	29.5	9.01	158	0.84	3.25	1	8	2	28	325	315	27	7.6
AXHN	8 Dec 92	0.271	0.25-4.8	1	17.4	122.28	11.79	32	9.29	147	1.4	2.28	1	15	10	17	345	320	16	6.7
AXHS	8 Dec 92	0.271	0.25-4.8	1	18.5	125.7	11.85	29.5	9.31	147	1.4	2.2	1	12	10	17	325	303	16	-
AXHN	6 Jan 93	0.191	0.25-4.14	1	16.8	100.92	9.84	32	9.27	148	3	1.8	1	8	11	18	470	451	17	20.5
AXHS	6 Jan 93	0.191	0.25-4.27	1	16.9	108.36	10.54	29.5	9.28	148	3	1.9	1	7	12	20	480	461	19	20.2
AXHN	9 Feb 93	0.236	0.25-4.3	1	15.5	89.75	8.99	32	8.96	151	3.5	1.85	0	8	7	21	595	580	21	23.5
AXHS	9 Feb 93	0.236	0.25-4.37	1	15.7	91.52	9.14	30.5	8.93	149	3.5	1.9	1	6	6	25	600	588	24	23.7
AXHN	9 Mar 93	0.196	0.25-6.4	1	16.1	75.04	7.38	32	9.09	148	0.79	2.9	1	4	2	16	390	384	15	9
AXHS	9 Mar 93	0.196	0.25-6.4	1	17.1	100.51	9.75	29.3	9.1	147	0.83	3.15	1	4	2	16	405	399	15	7.9
AXHN	6 Apr 93	0.191	0.25-5.87	1	13.7	88.85	9.27	32.5	8.89	157	0.65	2.55	0	4	9	16	410	397	16	6.1
AXHS	6 Apr 93	0.191	0.25-6.09	1	13.7	91.81	9.59	28.8	8.83	156	0.63	2.65	1	11	12	18	335	312	17	5.5
AXHN	4 May 93	0.216	0.25-11	1	10.9	84.95	9.44	32	8.34	162	0.59	4.78	2	20	19	16	475	436	14	3.5
AXHS	4 May 93	0.216	0.25-10.7	1	10.9	71.32	7.92	29.5	8.36	162	0.54	4.65	3	21	16	17	340	303	14	5.2
AXHN	15 Jun 93	0.491	8	1 Iso	8.2	67.17	7.97	32	7.78	167	0.77	5.45	34	125	32	51	555	398	17	3
AXHN	15 Jun 93	0.491	24	1 Iso	8.2	67.17	7.97	32	7.78	167	0.74	5.45	30	145	32	51	425	248	21	
AXHS	15 Jun 93	0.491	7.5	1 Iso	8.2	69.35	8.23	30.5	7.8	169	0.66	4.95	29	150	30	56	595	415	27	3.7
AXHS	15 Jun 93	0.491	22.5	1 Iso	8.2	69.35	8.23	30.5	7.8	168	0.71	4.95	34	155	30	53	575	390	19	

Notes: DO = dissolved oxygen; EC = electrical conductivity; Turb = turbidity; FTU = Formazin Turbidity Unit; DRP = dissolved reactive phosphorus; NH4 = ammonium; NO3 = nitrate; TP = total phosphorus; TN = total nitrogen; TON = total organic nitrogen; Pdiff = TP minus DRP; Chla = chlorophyll *a*; av = average. Layer codes: 1 = epilimnion; 1 Iso = isothermal condition; 2 = thermocline; 3 = hypolimnion.

Table 4.5 (b): Sample of final data file in layer format showing thermocline and hypolimnion data

Site ID	Date	Lake height (m)	Sampling depths (m)	Layer code	Av layer temp (¡C)	Av layer DO %	Av layer DO (mg/l)	Station depth (m)	pH	EC (µS/cm)	Turb (FTU)	Secchi depth (m)	DRP ppb P	NH4 ppb N	NO3 ppb N	TP ppb P	TN ppb N	TON ppb N	P Diff ppb P
Thermocline																			
AXHN	4 Mar 92	-0.001		2	11	22.8	2.4	33											
AXHS	4 Mar 92	-0.001		2	11.1	19.5	2	30											
AXHN	7 Apr 92	0.081		2	10.1	24.3	2.7	31.8											
AXHS	7 Apr 92	0.081		2	10.2	29.4	3.2	29.5											
AXHN	5 May 92	0.077		2	9.7	26.7	3	31.7											
AXHS	5 May 92	0.077		2	9.7	26.9	3	29											
AXHN	10 Nov 92	0.241		2	8.9	86.2	10.01	32											
AXHS	10 Nov 92	0.241		2	9.7	91.96	10.51	29.5											
AXHN	8 Dec 92	0.271		2	10	74.33	8.38	32											
AXHS	8 Dec 92	0.271		2	10.9	76.54	8.42	29.5											
AXHN	6 Jan 93	0.191		2	11.3	50.92	5.53	32											
AXHS	6 Jan 93	0.191		2	11	51.76	5.59	29.5											
AXHN	9 Feb 93	0.236		2	10.8	27.32	2.88	32											
AXHS	9 Feb 93	0.236		2	11.5	32.92	3.48	30.5											
AXHN	9 Mar 93	0.196		2	11.3	10.61	1.12	32											
AXHS	9 Mar 93	0.196		2	13.1	30.58	3.07	29.3											
Hypolimnion																			
AXHN	4 Mar 92	-0.001	22/27	3	8.5	6.8	0.8	33	7.22	180	1.2		173	475	2	215	675	198	42
AXHS	4 Mar 92	-0.001	22/26	3	8.7	5.9	0.7	30	7.25	177	0.8		120	225	70	135	490	195	15
AXHN	7 Apr 92	0.081	25.3/28.6	3	8.7	8.6	1	31.8	7.32	184	1.4		210	590	2	250	735	143	40
AXHS	7 Apr 92	0.081	24.8/27.1	3	8.6	7.9	0.9	29.5	7.38	190	1.2		235	645	1	265	750	104	30
AXHN	5 May 92	0.077	26.6/29.1	3	8.7	8	0.94	31.7	7.35	186	1.4		270	780	3	290	880	97	20
AXHS	5 May 92	0.077	25.6/27.3	3	8.8	7.4	0.9	29	7.35	184	1.1		205	635	4	265	840	201	60
AXHN	10 Nov 92	0.241	18/25	3	6.6	57.28	7.06	32	7.55	165	0.63		11	38	210	47	510	262	36
AXHS	10 Nov 92	0.241	20.5/25	3	6.8	63.83	7.82	29.5	7.63	164	0.47		15	15	210	42	445	220	27
AXHN	8 Dec 92	0.271	19.3/25.6	3	7	39.24	4.78	32	7.47	174	0.73		12	24	270	48	510	216	36
AXHS	8 Dec 92	0.271	17.8/23.6	3	7	41.16	5.01	29.5	7.52	173	0.74		14	15	250	47	490	225	33
AXHN	6 Jan 93	0.191	21.3/26.6	3	7.2	17.96	2.17	32	7.36	175	0.88		42	25	315	61	570	230	19
AXHS	6 Jan 93	0.191	19.8/24.6	3	7.3	24.07	2.91	29.5	7.42	174	0.66		21	12	310	53	520	198	32
AXHN	9 Feb 93	0.236	22	3	7.5	0.82	0.1	32	7.17	178	0.66		35	81	240	95	570	249	60
AXHN	9 Feb 93	0.236	25.5	3	7.5	0.82	0.1	32	7.78	179	0.73		54	150	155	115	585	280	61
AXHS	9 Feb 93	0.236	20.8	3	8.2	4.08	0.48	30.5	7.29	182	0.55		9	29	285	53	625	311	44
AXHS	9 Feb 93	0.236	27.2	3	8.2	4.08	0.48	30.5	7.22	180	0.51		24	60	280	82	570	230	58
AXHN	9 Mar 93	0.196	22	3	7.9	0	0	32	7.3	184	0.51		87	180	50	115	505	275	28
AXHN	9 Mar 93	0.196	27	3	7.9	0	0	32	7.26	184	0.53		111	260	15	140	545	270	29
AXHS	9 Mar 93	0.196	21.6	3	8.2	0	0	29.3	7.33	184	0.52		64	105	175	90	535	255	26
AXHS	9 Mar 93	0.196	25.2	3	8.2	0	0	29.3	7.29	184	0.48		105	235	11	130	500	254	25

Notes: DO = dissolved oxygen; EC = electrical conductivity; Turb = turbidity; FTU = Formazin Turbidity Unit; DRP = dissolved reactive phosphorus; NH4 = ammonium; NO3 = nitrate; TP = total phosphorus; TN = total nitrogen; TON = total organic nitrogen; Pdiff = TP minus DRP; av = average. Layer codes: 1 = epilimnion; 1 Iso = isothermal condition; 2 = thermocline; 3 = hypolimnion.

Chapter 5. Data processing

5.1 Intermediate data processing

Initial data processing of depth profile data –the setting up of the basic data file in layer format – was discussed in chapter 4. Lake Hayes data is shown in the examples in Table 4.5. This chapter explains the data processing to be carried out using that file. Lake Hayes data is used throughout this chapter and the results obtained thus enable Lake Hayes to be viewed as a case study.

Lake Hayes was monitored from March 1992 to June 1996 at two stations in the lake. Two of the recommendations given in section 1.5 are that (a) the lake year should run from September to August and (b) baseline monitoring should be carried out for a minimum of two years. Thus data from two stations for the period from March 1992 to August 1994 will first be analysed to check whether there is spatial correlation in the baseline data, as shown in the flowchart, Figure 4.2. This analysis determines how many stations are needed and an adequate sampling frequency for the lake by plotting the data obtained from one station against that from another station on the lake, taken on the same day and from the same depth. If the two data sets are found to correlate significantly at the 1% level or better (a p-value < 0.01) it can be concluded that the two stations give essentially the same data and only one station need be sampled.

The chart for Lake Hayes is shown in Figure 5.1. The results of the spatial correlation are given in Figure 5.2 where data from the south station are plotted against data from the north station. There is strong correlation shown in all five of the variables, so it can be concluded that the two stations are equivalent. Thus from September 1994 onward, only data from the north station will be used in the analysis of results. However, the lake chart indicates that a new monitoring station in the middle of the Jolly Basin could be established as the monitoring station for the lake.

The next issue to check is whether there is temporal correlation in the data – are the values of samples taken during one month related to those taken the month before? If they are, it might not be necessary to take samples each month. Figure 5.3 (B, E) shows that there is a lag correlation when the data for SD and DO from one month are compared with data taken at the same station on the previous month, whereas the data for Chla, TP and TN do not show significant temporal correlation. An approximation of the SD or DO value that would be measured during one month could be estimated from the previous month's observation. However, this estimate would not be good enough to determine year-to-year changes in the data. Since the purpose of monitoring is largely to determine year-to-year trends in the data in spite of the seasonal pattern, sampling must be frequent enough to give confidence in the values obtained for each year. Thus a one-month lag test for temporal correlation does not resolve the issue of concern in long-term monitoring, which is the determination of change in trophic level index values values with time. Determination of sampling frequency remains a matter of available resources and inspection of the seasonal patterns for each variable. Frequency of sampling for routine monitoring should be monthly if possible; the number of samplings can be reduced, if necessary, either by having non-sampling years or by dropping out some months when there is little change in the variables being monitored. This matter is discussed further in section 5.2.3.

5.2 Plots of important data

The flowchart (Figure 4.2) shows that at this point in calculating results from the basic data file, either time trend plots of data can be obtained or the TLx and TLI values calculated. The plots will be done next because they promote familiarity with the data being analysed. The first plots to be examined will be those for lake height, epilimnion plus isothermal temperatures, hypolimnion temperatures and DO. The detection of time trends has been mentioned briefly in section 1.6 but will be described here in more detail.

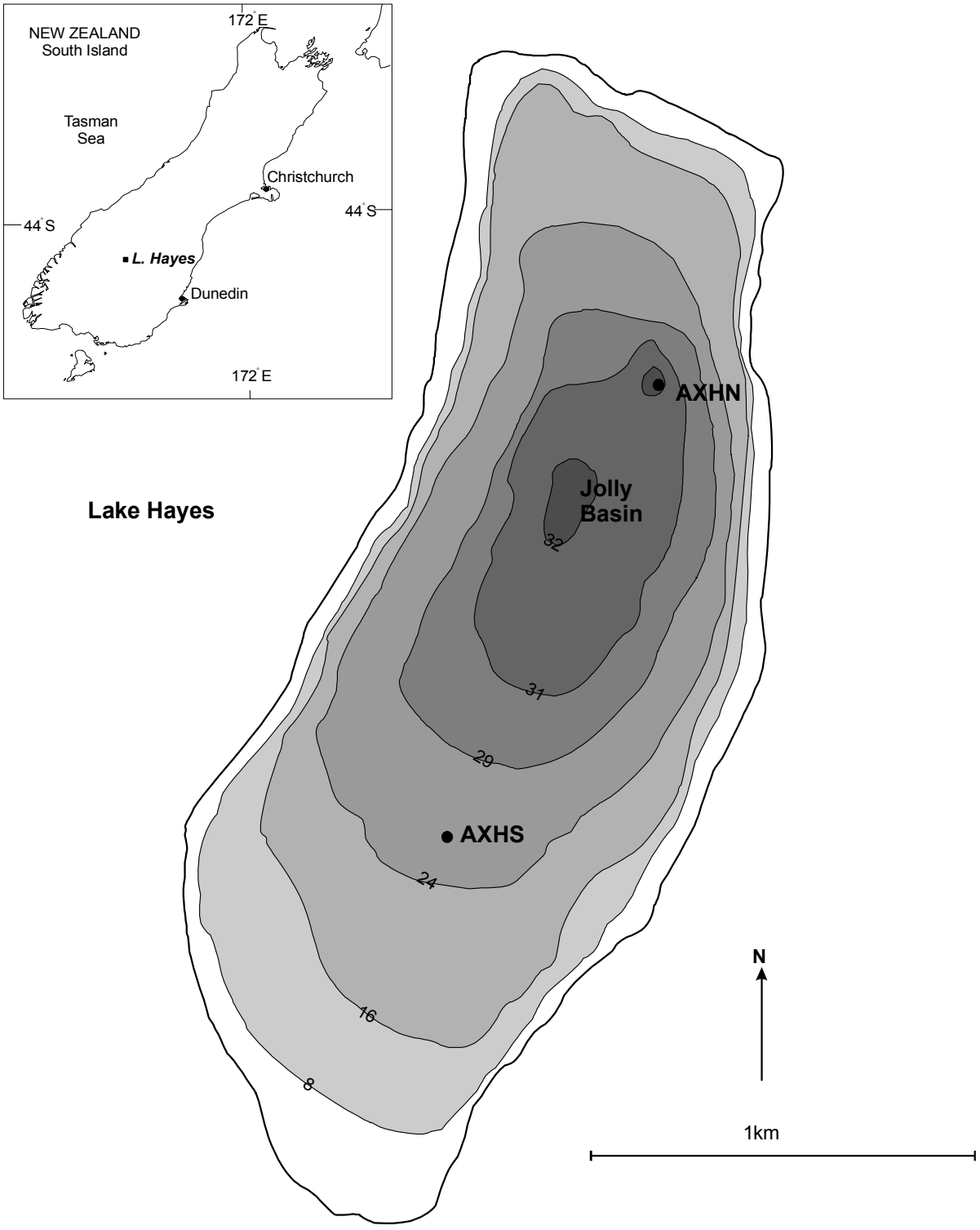


Figure 5.1: Lake Hayes showing the positions of the sampling stations: AXHN, chart depth 33.3 m, and AXHS, chart depth 26 m

Trend detection

The prime objective of the data analysis is to detect a significant change in any parameter with time. The data on the trophic state variables, Chla, SD, TP and TN, are deseasonalised before fitting a trend line so as to increase the sensitivity of the trend detection procedure, as described below. If there are

three or more years of data available for a lake, it is possible to carry out a valid deseasonalising procedure on the data.

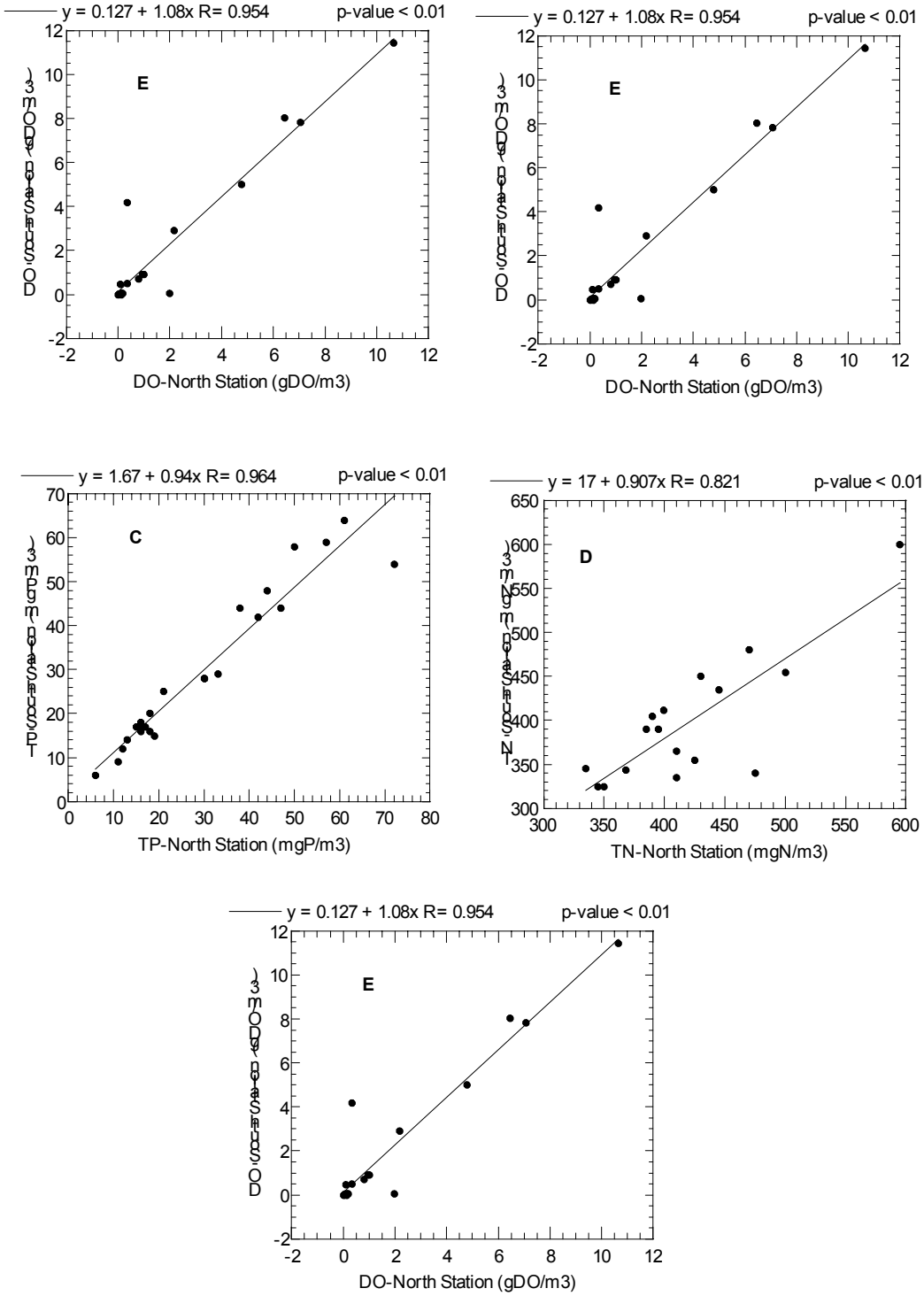


Figure 5.2: Plots to check for spatial correlation between the data collected from the south and north stations of Lake Hayes

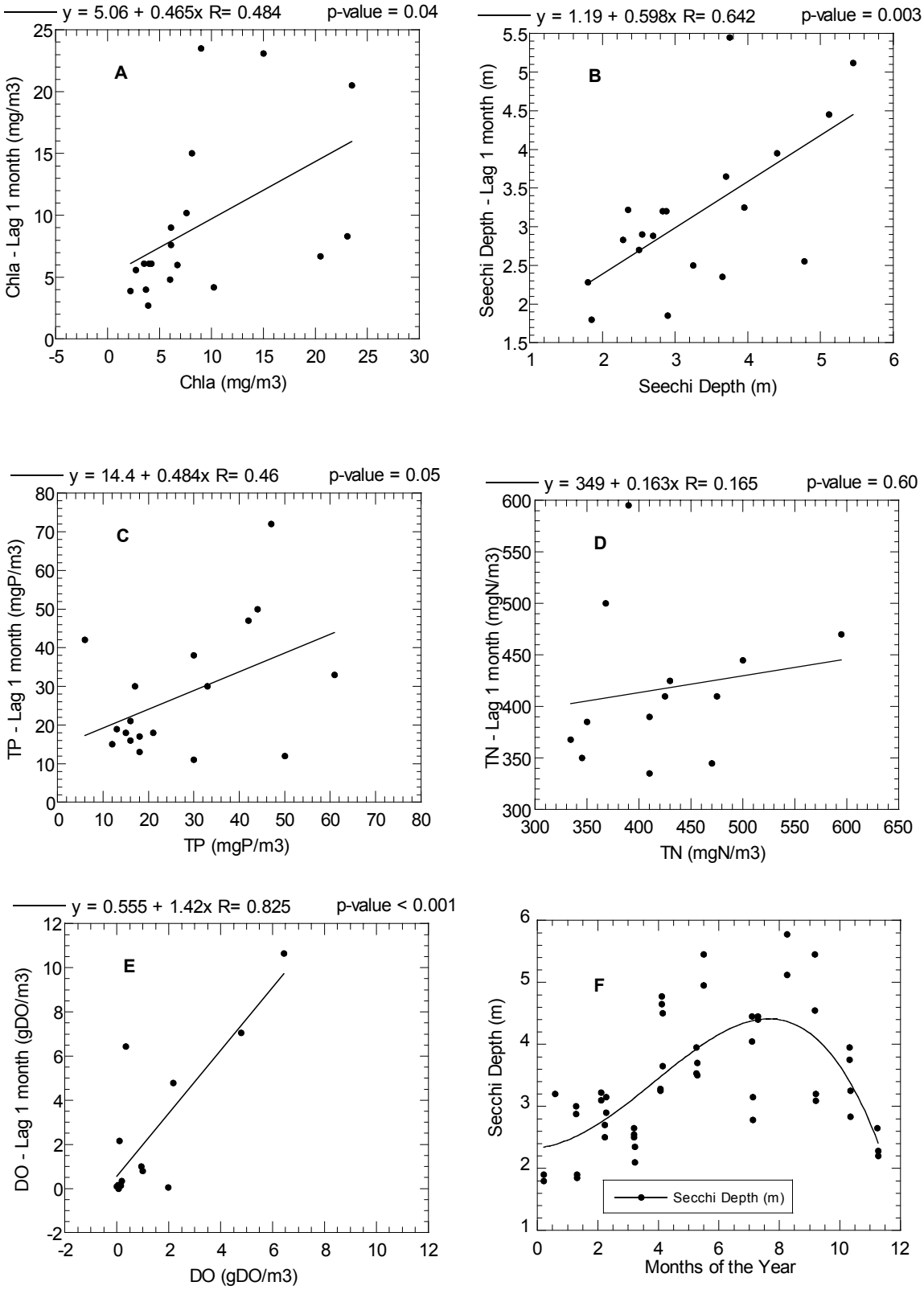


Figure 5.3: Plots showing (A to E) the temporal correlation in Lake Hayes data plotted with a lag of one month and (F) the seasonal pattern in Secchi depth observations

Temperature provides a good example of the data analysis procedures used and is reported here because the change of temperature of the water of the lake during the year is relatively large and similar from year to year. Figure 5.4C shows the epilimnetic temperatures which have been observed during the four years of monitoring plotted only as a function of the time of year of collection with no regard for the year of collection. This process is called annualising the data. A polynomial curve was fitted to the annualised data as shown in Figure 5.4C. The residual, deseasonalised value for any particular day is the observed value less the day/month value calculated from the polynomial for its day of observation. A non-sinusoidal formulation of the seasonal pattern was chosen because, although change in temperature with time is sinusoidal in nature, the patterns of change in Chla, SD, TP and TN with time are frequently irregular.

The observed and residual data are plotted against time as shown in Figure 5.4D and straight-line plots are fitted to the data using ordinary least square regressions. A *p*-value is then calculated for the lines fitted to the observed and residual data. A low *p*-value means that there is a low probability that the fit of the line is attributable to chance. (In other words, a low *p*-value means that there is a low possibility of observing a trend at least as large as the value calculated when there is no trend in the data.) The LakeWatch program (Knowlysis, 1998) can carry out all the necessary calculations. This program permits selection of a polynomial of any order (up to the twentieth) for a curve-fit to the annualised data. The program then automatically calculates the residuals and plots them and the observed data as a function of their true date of collection. It then fits a linear least squares regression line to both sets of data and calculates the *p*-values of the linear fits. First the program annualises the selected data, calculates the second-order polynomial to fit the annualised data, calculates the residuals, fits regression lines to the observed data and residuals and calculates p-values of the regression lines. The order of the polynomial fit to the annualised data is then increased by one, noting the *p*-value resulting from the regression line fit to the new residuals. This procedure is continued until the polynomial is found the order of which gives the lowest resulting *p*-value to the linear regression fit to the residual data. (This is usually a fourth- to eight-order polynomial. Use of higher order polynomials do not usually result in lower *p*-values for the linear regression on the residuals.) The procedure is thought to reveal the maximum amount of seasonality that can be removed from the data. Either LakeWatch or the procedures outlined in sections 1.6, 1.7, 5.2 and 5.3 can be used to analyse the lake monitoring data. The procedures and results generated from their use have been published in the scientific literature (Burns *et al*, 1999).

Because the units of the *x*-axis of Figure 5.4D are years, the slopes of the lines designate the change per year in the variables and the *p*-values give the smallest significance level that allows the null hypothesis of no trend to be rejected. The equation for the residual straight line has a slope of 0.217 indicating that the temperature of Lake Hayes increased at $0.22^{o}C\ year^{-1}$. For the line fitted to the residual data in Figure 5.4D with a p-value < 0.01, there is a less than 1% chance of observing a slope as large as $0.22^{o}C\ year^{-1}$ when there is no trend in the data. However, for the line fitted to the observed data there is a greater than 10% chance of observing a slope as large as $0.36^{o}C\ year^{-1}$ when there is no trend in the data. The variability removed from the data by the deseasonalising procedure enables trends with time to be determined with more confidence. Residuals have been calculated and straight lines plotted for both residuals and observed data for temperature and for the four variables that are the most informative about trophic state: Chla, SD, TP and TN.

It should be noted that lower *p*-values are obtained with a higher number of samples. Thus the number of samples in a trend detection study needs to be kept in mind because low *p*-values can easily be obtained in cases where many samples have been taken, even with relatively low correlation coefficients. The number of samples taken from each lake has been mentioned for this reason. The significance level for establishing that a trend has been detected is taken at 5% ($p \leq 0.05$) for this data set for Chla, SD, TP and TN where generally between 100 and 200 epilimnion and isothermal samples have been taken over four years of monitoring. HVOD rates were also calculated for stratified lakes and these rates were plotted as a function of the year when they were obtained. A linear regression line was fitted to these values and a *p*-value calculated for the line. The significance level for the HVOD time trend was set at 20% (p-value < 0.20) because, although four years of data on a lake would yield between 100 and 200 values for Chla, SD, TP or TN, it would yield only four HVOD rates.

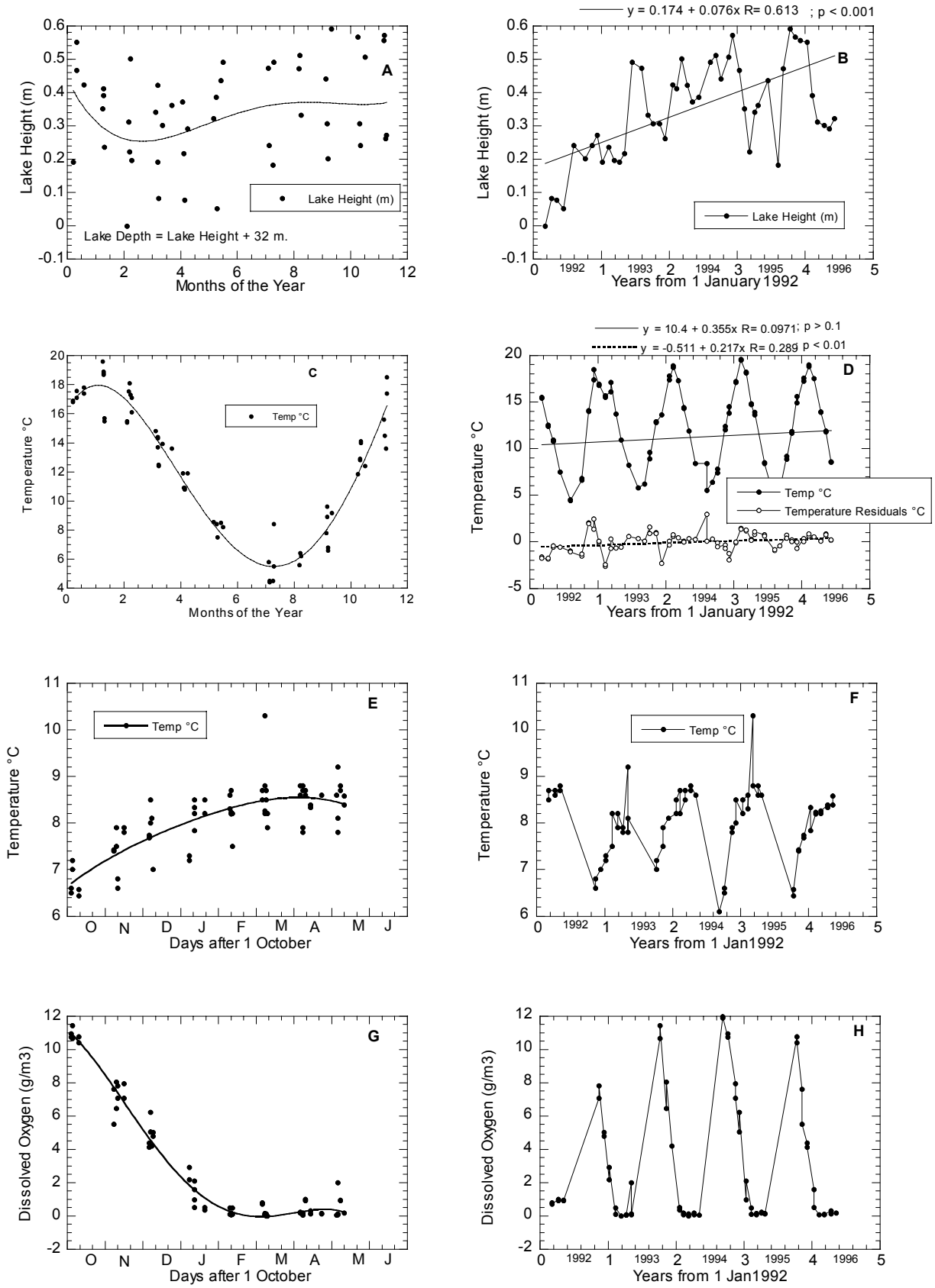


Figure 5.4: Plots of epilimnion annualised data (A, C), epilimnion time trend data (B, D), hypolimnion annualised data (E, G) and hypolimnion trend data (F, H) for Lake Hayes

Table 5.1 is a summary of the temperature results for the NZLMP data. They are consistent, with all the lakes reporting the same type of change; as might be expected with a climatic change operating over the whole country. The average temperature change observed was $0.35^{o}C \pm 0.14^{o}C$ per year, indicating that the analytical technique used to calculate temperature trends gives consistent results. The determination of the time trend in temperature in the lakes is relatively unimportant from the point of view of changes in the trophic state of the lakes. However, it is important in that it indicates that the deseasonalising techniques used are sensitive in observing a relatively small degree of change in data that have a large annual variation. The same deseasonalising and trend analysis techniques used with the temperature data were used on Chla, SD, TP and TN data.

Table 5.1: Observed trends of change with time in New Zealand lake epilimnion temperatures, February 1992 to June 1996

Lake	Change in temperature (^{o}C $year^{-1}$)
Shallow or intermittently stratified lakes	
Omapere	0.42
Whangape	(+0.09)
Hamilton	0.31
Maratoto	0.15
Rotorua	0.3
Pearson	0.59
Forsyth	0.64
Alexandrina	(+0.13)
Stratified lakes	
Taharoa	0.24
Pupuke	0.33
Rotoiti NI	0.22
Okareka	0.35
Okataina	0.26
Tarawera	0.46
Rotokakahi	0.35
Tutira	0.39
Brunner	(-0.06)
Hayes	0.22
Average	0.35
Std dev	0.14

Note: Non-significant changes are in brackets.

Plots of lake level, temperature and DO data

Figure 5.4 shows results from some of measurements of four variables from Lake Hayes. Figure 5.4A shows height measured above 0.00 m on a lake-level gauge. No real seasonal pattern is seen but Figure 5.4B shows that the level of the lake increased from 1992 to 1996. Figure 5.4C shows a normal annual pattern of epilimnetic temperature change and Figure 5.4D shows the temperature increase from 1992 to 1996. Figure 5.4E shows that the temperature in the hypolimnion increased during each stratified season but Figure 5.4F shows no apparent change in the hypolimnion temperature with time. Figure 5.4G shows that the hypolimnetic DO declined from near saturation values in October to anoxic conditions in February and continued in that state until May. Figure 5.4H shows how this pattern was repeated each year.

Plots of data from the four key variables

Figure 5.5 (A, B) shows that Chla changed little with season but had declined from high values in 1992 to lower, but unchanging, values over the remaining three years. Figure 5.5 (C, D) shows that SD was seasonal in pattern to some degree but was unchanging over the four years of monitoring. Figure 5.5E shows that TP exhibits a strong seasonal pattern because of the hypolimnetic TP mixing upward at the end of the stratified season in June. Figure 5.5F shows a significant steady decline in TP with time. Figure 5.5 (G, H) shows a weak seasonal pattern in TN and a significant decline in the variable over time. The information shown in the figure illustrates the importance of looking at the results together. The downward trend in Chla is not very convincing, but when it is corroborated by the TP and TN declines, it becomes more likely that there has been a decline in the nutrient content of the epilimnion of Lake Hayes.

The annualised plots show the following characteristics:

Chla (Figure 5.5A) – there is very little change throughout the year, therefore months for sampling could be omitted at any time.

SD (Figure 5.5C) – the change during the year is smooth, thus sampling months could be omitted at any time of the year.

TP (Figure 5.5E) – concentrations change little between December and April and then change rapidly to a maximum value in May, June or July. Sampling during these three months is thus essential. Thereafter concentrations decline in a reasonably regular pattern from August to December, except that values seem to be quite variable in September.

TN (Figure 5.5G) – concentrations change fairly smoothly all through the year except for May and presumably June (June was not sampled) when concentrations can be quite variable.

DO (not shown) – concentrations change rapidly from October to January, with anoxic conditions prevailing from then to May.

Considering the sampling requirements of each of the five key variables, it would seem that the months February, April and August could be missed in the interest of reducing sampling costs, without serious damage being done to the quality of the data being collected.

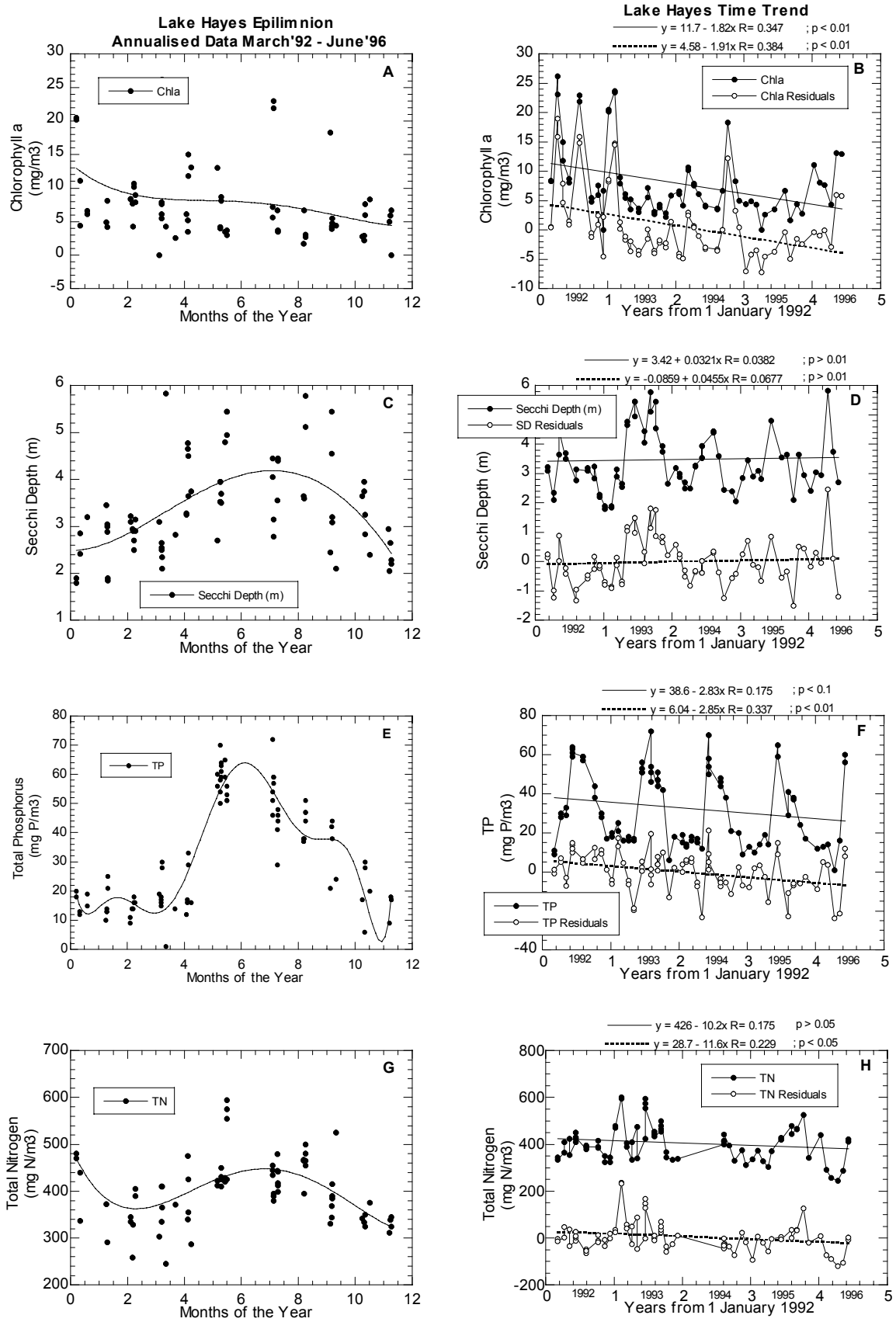


Figure 5.5: Annualised and time trend plots of the four key epilimnetic variables in Lake Hayes

HVOD rates

The fifth key variable is DO, and the HVOD rates are now calculated for the four summers when the lake was monitored. The HVOD plots are shown in Figure 5.6 and the observed HVOD rates are given by the slopes of the equations to the DO depletion rate trend lines. These values and the average hypolimnion temperatures during the periods of HVOD rate measurement are shown in Table 5.2. 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 standard temperature chosen for the Lake Hayes hypolimnion is 7.5°C because this temperature results in minimum change in the rates when adjusting them from the observed values to temperature-adjusted values. The temperature-adjusted rates are also shown in Table 5.2. The equation used in adjusting the rates (Burns, 1995) is:

$$HVOD_{std} = HVOD_{obs}\ 1.0718^{(Tstd - Tobs)} \qquad \textit{equation (8)}$$

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

$HVOD_{std}$ = HVOD rate at the standard temperature

The results in Figure 5.7 show that there was no significant trend ($p > 0.20$) in the HVOD rates from 1992 to 1996.

Table 5.2: Observed and adjusted HVOD rates for Lake Hayes from 1992 to 1993

Summer	Average temperature (¡C)	Observed DO depletion rate (mg m^{-3} day^{-1})	Observed rate at 7.5¡C (mg m^{-3} day^{-1})
1992/93	6.68	89.4	94.6
1993/94	7.78	101	99.1
1994/95	7.73	87.3	85.9
1995/96	7.42	100	101
Averages	7.4	94.4	95.2

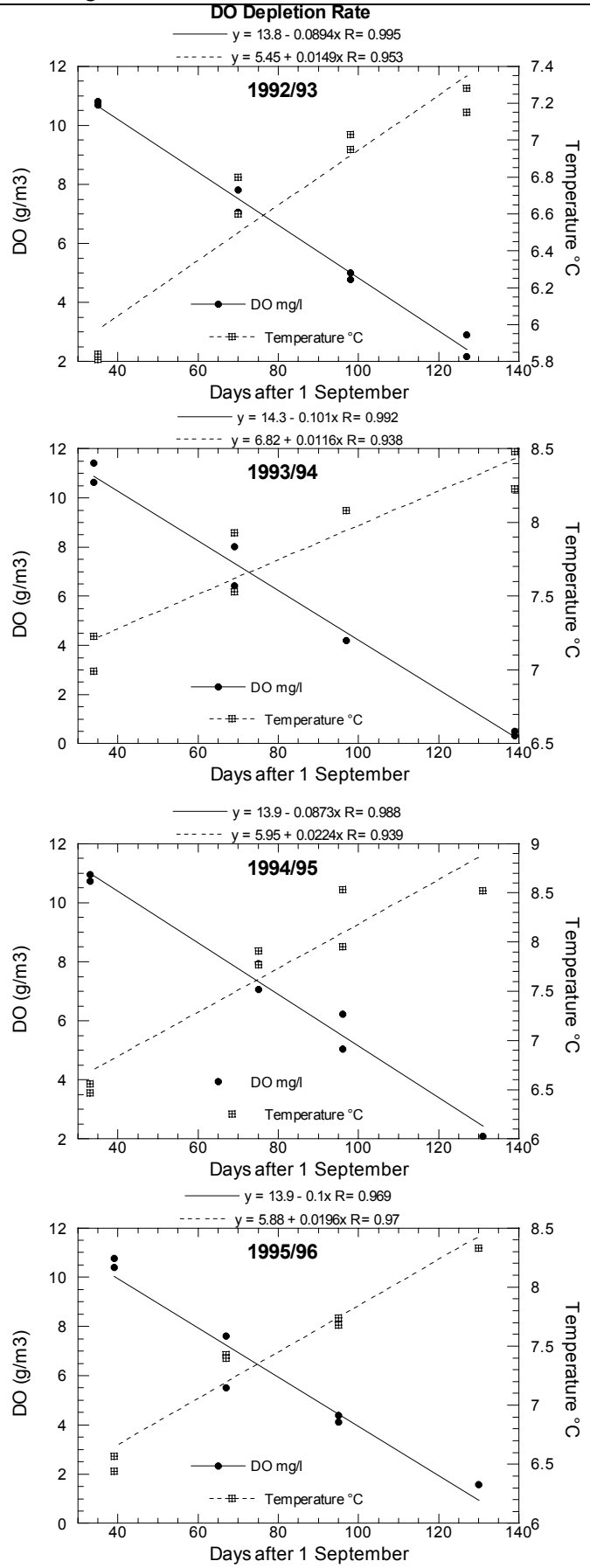


Figure 5.6: Seasonal DO and temperature plots for the calculation of HVOD rates for Lake Hayes from 1992 to 1996

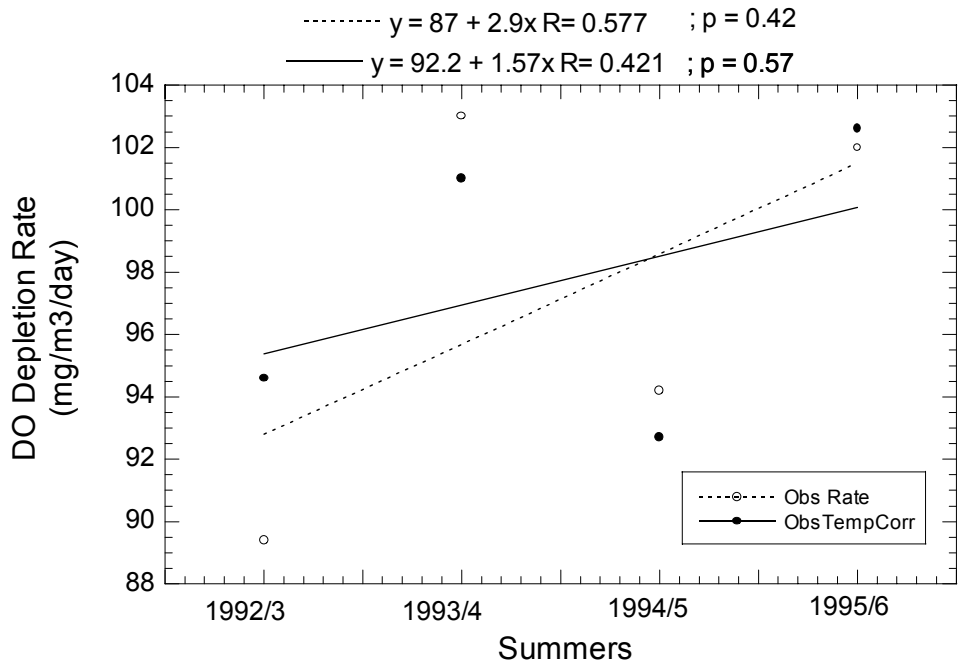


Figure 5.7: Plots of observed HVOD rate and the HVOD rate corrected to a standard hypolimnion temperature of 7.5°C for Lake Hayes from 1992 to 1996

5.3 PAC and TLI results

The PAC values are next calculated using the annual change values obtained from the slopes of the key variables showing significant change. This calculation is described in section 1.6. These values are obtained by dividing the annual change value for a variable by its average value for the period of observation (Figure 5.5, Table 5.3). For example, the annual change in Chla of -1.91 mg m^{-3} $year^{-1}$ when divided by the average value for the period of observation of 7.62 mg m^{-3} yields a PAC value of –24.9% $year^{-1}$ (Table 5.4). The PAC values for each variable and average PAC values are some of the most important information obtained on the lake and these results are shown in Table 5.4. The four epilimnion variables all show trends toward lower trophic level although the SD trend was small and non-significant. Only PAC values calculated from significant trend lines are considered indicative of change in a particular variable. The PAC values for the different variables are expressed in the same units (% change per year) and thus can be averaged with a *p*-value calculated for the average as shown in Table 5.4. The PAC values calculated from non-significant slopes are replaced by a value of 0.0. Changes indicating increased eutrophication are assigned positive values and changes indicating decreased eutrophication are given negative values.

The decision on whether a lake has changed over time is made by examining the *p*-value of the PAC average. The assessment is made as to the probability of change having occurred by using the ranges of these *p*-values as shown below:

p-*value range of PAC average*

< 0.1: definite change

0.1–0.2: probable change

0.2–0.3: possible change

> 0.3: no change

The next important values that need to be calculated are the TLI values as described in section 1.7. The annual average values are taken from the three complete years of data shown in Table 5.3 (the normal September to August lake-year) because only complete years of data can be used in calculating TLI values. The TLx values and the TLI values generated from these numbers are shown in Table 5.5, as are the average TLI values from the two most recent years of data and the TLI trend line derived from the TLx values.

Table 5.3: Annual and period epilimnion and hypolimnion averages for Lake Hayes from 1992 to 1996 plus the averages for the whole period for all measured variables

	Date	Lake depth (m)	Average temp (¡C)	Average DO (% sat)	Average DO (mg litre^{-1})	Chla ppb P	Secchi depth (m)	TP ppb P	TN ppb N	Pdiff ppb P	TON ppb N	DRP ppb P	NH4 ppb N	NO3 ppb N	pH	EC (µS/cm)	Turb (FTU)
Epilimnion or isothermal																	
Averages	Mar 92ĞAug 92	32.11	9.0	91.2	10.7	15.5	3.23	44.4	393	21.1	281.0	23.2	90.9	21.4	8.3	164	1.4
Std dev		0.09	4.0	9.1	1.5	7.4	0.61	20.1	34	8.8	60.2	19.2	67.3	18.0	0.5	4	0.7
Averages	Sep 92ĞAug 93	32.31	10.8	91.1	10.2	8.6	3.72	35.3	444	19.1	335.6	16.2	69.3	38.7	8.4	160	1.1
Std dev		0.12	4.6	16.5	1.5	6.9	1.31	16.7	82	5.3	102.5	15.3	68.4	34.8	0.6	8	0.9
Averages	Sep 93ĞAug 94	31.25	11.1	87.3	9.7	5.7	3.58	30.7		15.8		15.0	57.4	57.3	8.0	151	0.8
Std dev		6.10	4.6	21.5	2.5	2.2	0.95	18.2		8.0		13.2	41.3	71.5	1.7	29	0.3
Averages	Sep 94ĞAug 95	32.39	11.0	93.6	10.4	5.6	3.35	29.0	401	17.4	313.0	11.7	55.3	32.8	8.5	156	1.0
Std dev		0.12	5.2	12.9	1.7	3.7	0.75	17.0	60	5.7	49.1	13.4	47.7	35.3	0.6	7	0.5
Averages	Sep 95ĞJun 96	32.42	13.3	92.1	9.7	6.9	3.22	25.3	338	16.2	276.9	9.1	39.1	21.5	8.7	148	0.7
Std dev		0.13	3.8	20.0	2.1	3.6	1.00	19.8	90	13.3	77.9	7.6	41.0	31.6	0.7	8	0.2
Averages	**Mar 92ĞJun 96**	**32.34**	**11.21**	**92**	**10.15**	**7.62**	**3.46**	**32.2**	**399**	**17.8**	**299.9**	**14.4**	**60.1**	**36.5**	**8.44**	**157**	**1.00**
Std dev		0.15	4.62	16	1.76	5.68	0.96	18.7	77	8.2	80.3	14.5	55.0	46.2	0.67	8	0.64
Hypolimnion																	
Averages	Mar 92ĞMay 93		8.7	7.4	0.9			236.7	728	34.5	156.3	202.2	558.3	13.7	7.3	184	1.2
Std dev			0.1	1.0	0.1			55.6	138	16.4	48.3	51.7	190.6	27.6	0.1	5	0.2
Averages	Nov 92ĞMay 93		7.7	12.0	1.5			108.8	568	35.2	238.3	72.0	192.5	126.6	7.4	181	0.6
Std dev			0.6	19.7	2.4			48.3	75	18.4	60.4	51.1	161.1	127.4	0.1	7	0.1
Averages	Oct 93ĞMay 94		8.3	16.3	2.0			101.8		18.1		83.7	229.2	159.0	7.3	172	0.6
Std dev			0.5	30.3	3.7			54.5		16.0		54.3	189.7	149.2	0.3	4	0.2
Averages	Sep 94ĞApr 95		8.3	23.9	2.9			100.4	619	22.7	258.2	77.6	302.7	57.7	7.4	166	0.9
Std dev			1.0	34.6	4.3			61.0	187	15.9	68.7	51.2	184.6	59.4	0.4	4	0.3
Averages	Oct 95ĞMay 96		7.9	21.1	2.6			115.1	552	18.7	246.1	96.4	264.5	41.9	7.4	162	0.8
Std dev			0.6	30.1	3.7			80.8	193	14.1	82.5	75.9	223.1	54.9	0.2	9	0.4
Averages	**Mar 92ĞMay 96**		**8.1**	**17.8**	**2.2**			**114.0**	**593**	**24.8**	**239.8**	**89.0**	**269**	**92.4**	**7.36**	**171**	**0.75**
Std dev			0.8	28.5	3.5			67.6	163	17.5	77.2	63.7	204	113.4	0.28	9	0.31

Notes: DO = dissolved oxygen; Chla = chlorophyll *a*; TP = total phosphorus; TN = total nitrogen; Pdiff = TP minus DRP; TON = total organic nitrogen; DRP = dissolved reactive phosphorus; NH4 = ammonium; NO3 = nitrate; EC = electrical conductivity; Turb = turbidity; FTU = Formazin Turbidity Unit; Std dev = standard deviation.

Table 5.4: PAC values of the key variables and related information

Lake Hayes	Chlorophyll *a*	Secchi depth x -1	Total phosphorus	Total nitrogen	HVOD
Annual change	-1.91	-0.05	-2.85	-11.6	1.57
(Unit of annual change)	(mg m^{-3} $year^{-1}$)	(m $year^{-1}$)	(mg m^{-3} $year^{-1}$)	(mg m^{-3} $year^{-1}$)	(mg DO m^{-3} day^{-1} $year^{-1}$)
p -value of annual change	<0.01	>0.1	<0.01	<0.05	0.57
Period average value	7.62 (mg m^{-3})	3.46 (m)	32.2 (mg m^{-3})	399 (mg m^{-3})	95.2 (mg DO m^{-3} day^{-1})
Percent annual change (PAC)	-24.9 % $year^{-1}$	(-1.4 % $year^{-1}$) = 0	-8.9 % $year^{-1}$	-2.9 % $year^{-1}$	(1.6 % $year^{-1}$) = 0
Average PAC	-7.36 % $year^{-1}$ with a *p* -value = 0.19				

Notes: values in brackets are not significant.

Table 5.5: TLI values for Lake Hayes for the years August 1992 to September 1995

Period	Chla (mg m^{-3})	SD (m)	TP (mg m^{-3})	TN (mg m^{-3})	TLc	TLs	TLp	TLn	TLI
Sep 92ĞAug 93	8.6	3.72	35.3	444	4.60	3.71	4.72	4.36	4.35
Sep 93ĞAug 94	5.7	3.58	30.7		4.14	3.75	4.55		4.15
Sep 94ĞAug 95	5.6	3.35	29.0	401	4.11	3.82	4.47	4.23	4.16
Averages	6.6	3.6	31.7	422.4	4.3	3.8	4.6	4.3	
TLI average (1994Ğ95) = 4.15 TLI units with a std error of 0.09									
TLI timetrend = -0.10 TLI units $year^{-1}$ with a std error of 0.12 and a *p* -value 0.47									

Notes: Chla = chlorophyll *a*; SD = Secchi depth; TP = total phosphorus; TN = total nitrogen; TLc = the trophic level value calculated from the Chla annual average etc.

The determination of trophic level and change of trophic level is done next following the concepts outlined in section 1.7. The PAC value for the 4.25 years of monitoring Lake Hayes is -7.4% $year^{-1}$ with a *p*-value of 0.19, which means that the lake is probably changing to a lower trophic state (Table 5.4). TLI has a time trend value of -0.1 ± 0.12 units $year^{-1}$ (Table 5.5). 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 Lake Hayes is probably becoming less eutrophic at the rate of 0.1 ± 0.12 TLI units $year^{-1}$. The most recent TLI value (1994–95) for the lake is 4.15 TLI units which classifies the lake as eutrophic. The PAC and TLI trends should be confirmed by some more years of monitoring.

5.4 Selection of appropriate time trend periods

The production of the large-scale printouts for data surveillance was addressed in section 4.5 with an example of such printouts shown in Figure 4.3. These printouts are used in selecting the appropriate periods for the calculation of trend lines. It is important not to extend trend lines from years where a particular trend is evident to other years where the trend no longer exists. The trend to lower temperatures seen at the end of 1995 in Figure 4.3 (a) is seen in Figure 4.3 (b) to persist through to 1996. This means that the 1997 temperature data will have to be inspected with particular care to determine whether the emerging trend to lower temperatures is a new trend to lower temperatures. The 1997 temperatures could fit into the earlier trend to higher temperatures, indicating that the May 1995–June 1996 lower temperature residuals were the result of a brief period of aberration during a period of increasing temperatures.

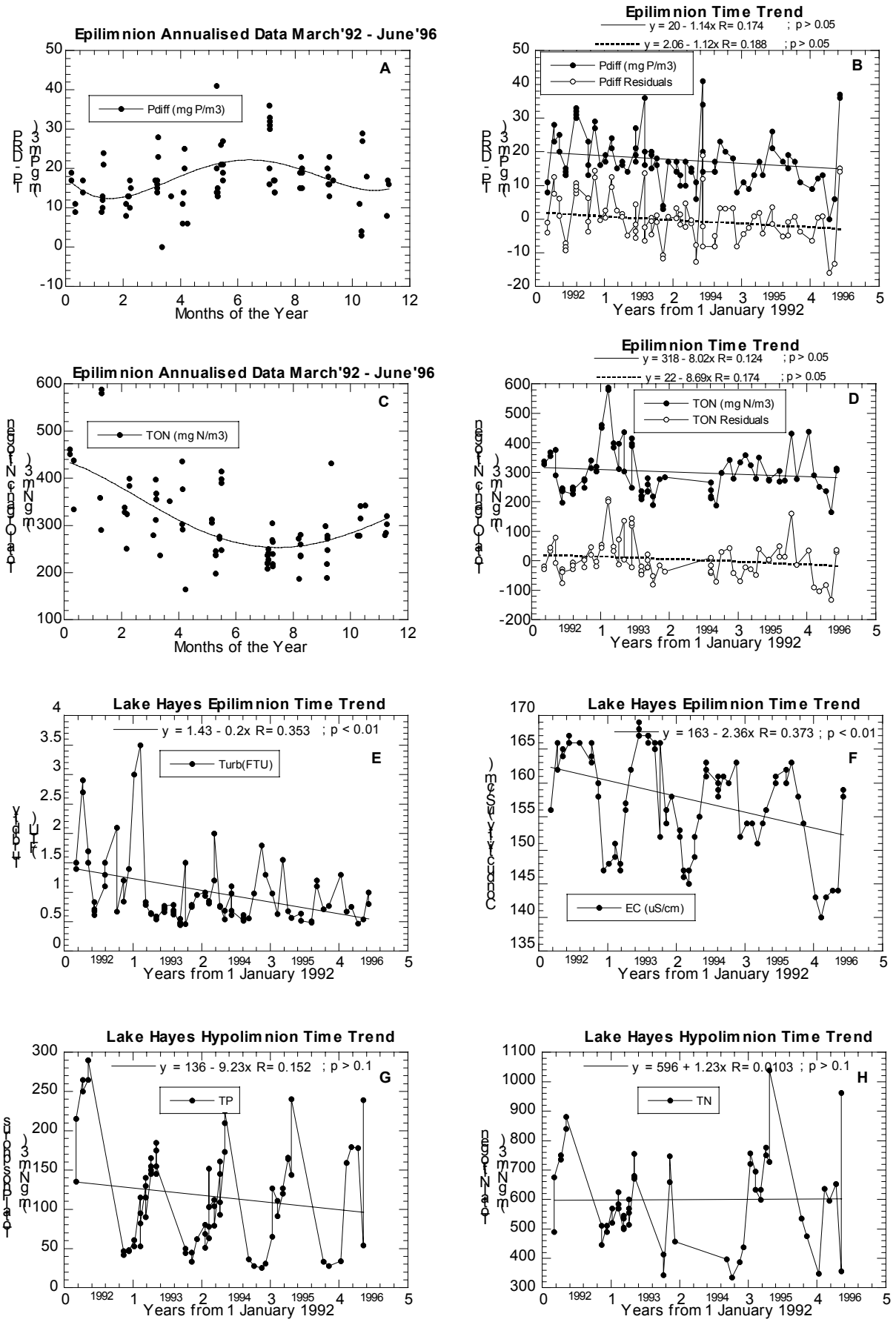


Figure 5.8: Plots of data of background variables in Lake Hayes

5.5 Plots of non-essential data

Several variables other than those termed the key variables were monitored as part of the programme. These are plotted out and if they add relevant information to an understanding of the process of change in the lake, receive comment. Figure 5.8 (A, B, C, D) shows plots of the organic components of TP and TN: Pdiff (TP minus DRP) and TON (TN minus NH_4 minus NO_3). Pdiff and TON show non-significant downward trends, as do TP and TN; thus the decline in TP and TN is probably the result of declines in both their soluble nutrient and organic components.

The turbidity plot, Figure 5.8E shows a significant decline with time in its observed values, in agreement with the decline in Chla. This is of interest because it provides an indication that the non-significant increase in SD is probably a meaningful increase even if not statistically significant. Conductivity, Figure 5.8F, also shows a significant decline in its observed values. This is of interest but, because conductivity is not directly related to the key trophic state variables, it is difficult to know if this decline is related to the decrease in trophic level. Figure 5.8G shows a plot of the observed hypolimnetic TP concentrations with some evidence of decline, in agreement with the epilimnetic TP trend, but this trend is not significant. However, there is a strong seasonal pattern in the hypolimnetic TP values and if they were annualised and their residuals plotted, hypolimnetic TP would almost certainly show a significant downward trend. The hypolimnetic TN values, Figure 5.8H, show no hint of any tend.

Epilimnetic NO_3, Figure 5.9A, did not show any trend of change with time but the hypolimnetic NO_3, Figure 5.9B, shows a decrease with time. This is of interest but, because all hypolimnetic NO_3 is denitrified to zero levels by the end of the stratified season, it does not add to epilimnetic concentrations of NO_3. Epilimnetic NH_3 concentrations, Figure 5.9C, show a weak, but non-significant decline with time of about 5.2 mg N m^{-3} $year^{-1}$. It is of interest that this rate is a little under half the rate of decline of TN, Figure 5.5H, at 11.6 mg N m^{-3} $year^{-1}$, indicating that much of the decline in TN is from a probable decline in NH_3. Hypolimnetic NH_3, Figure 5.9D, shows no discernible rate of change. Epilimnetic DRP, Figure 5.9E, shows a non-significant decline of 1.68 mg P m^{-3} $year^{-1}$ which is about half the decline observed in TP in Figure 5.5F, at 2.85 mg P m^{-3} $year^{-1}$, again indicating that much of the decline in TP is due to a probable decline in DRP. Figure 5.9 (G, H) 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 the epilimnetic or hypolimnetic pH showed any trend with time.

The plots shown in this chapter are the most important ones, but are by no means the only ones that could or should be done. Other graphs can be tried when a change in a lake is seen or an unexpected change in a variable is observed. The plots shown in Figures 5.8 and 5.9 are only an example of how data can be explored in more detail. Exploratory data examination should be done exhaustively when a major change has been observed and a special investigation is being planned to confirm the cause of an observed change. Careful analysis of routine monitoring data can provide valuable insights into processes in a lake.

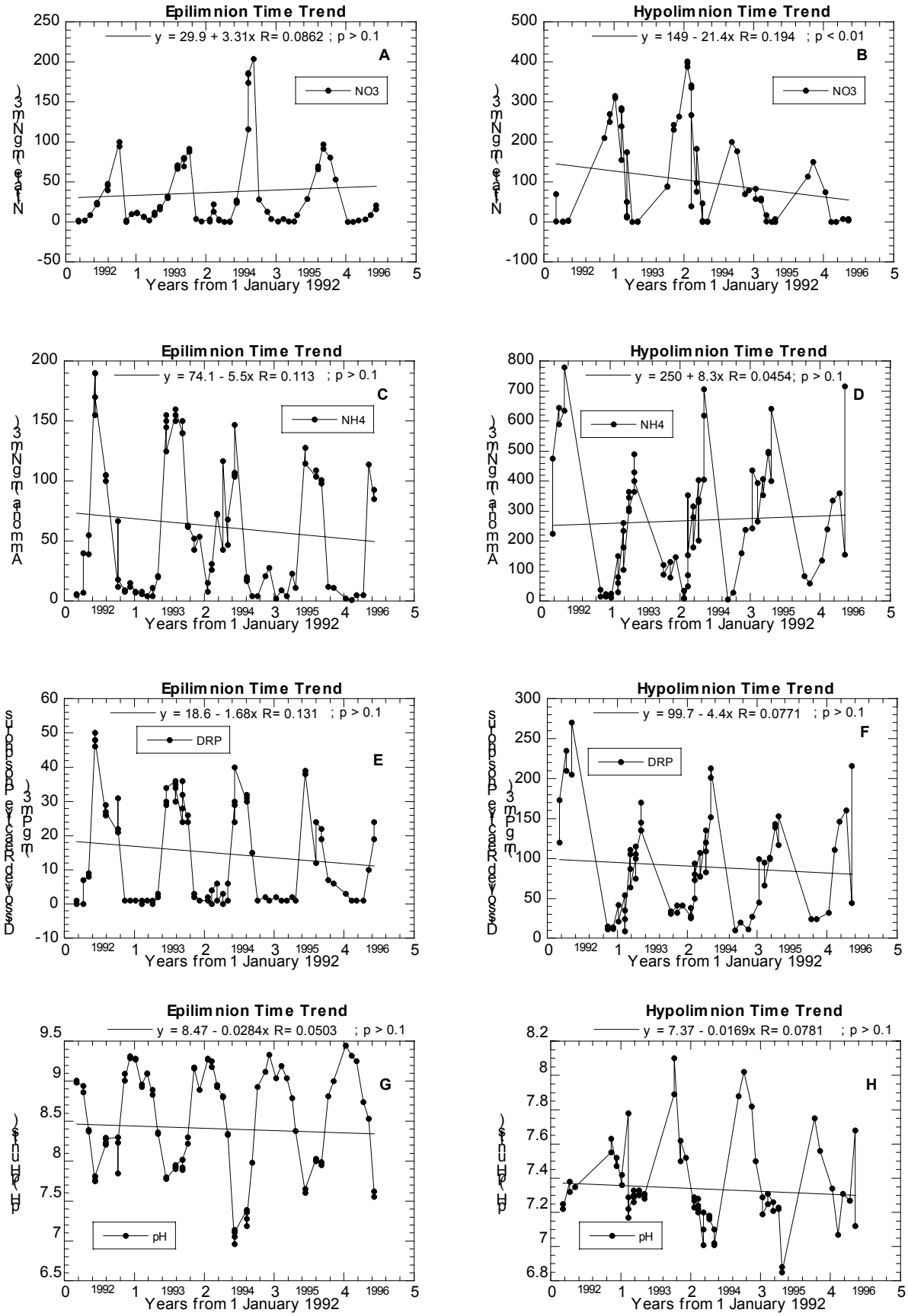


Figure 5.9: Plots of epilimnetic and hypolimnetic concentrations of soluble nutrients and pH conditions in Lake Hayes

Chapter 6. Case studies of trophic level and ecological change

This chapter presents case studies of lake monitoring results to show how the data may be interpreted in terms of change in trophic state, limiting nutrients or overall water quality and ecological condition. First it discusses three lakes illustrating trophic level change:

- Hamilton Lake, Waikato region
- Lake Omapere, Northland region
- Lake Okataina, central North Island region

Then a discussion is presented of Lake Okareka, central North Island, as an example of using lake monitoring data to provide a detailed report on the ecological status of a lake that appears to be changing slowly from an oligotrophic to a mesotrophic condition. Lastly, Lake Rotorangi, Taranaki region, offers an example of interpreting monitoring data to determine the trophic state of a reservoir.

6.1 Case studies of trophic level change

All possible plots and graphs will not be displayed in these case studies, but only those relating to the key variables and those illustrating a point of particular importance. Figures 5.8 and 5.9 in the previous chapter illustrate the plots that can be done when further exploration of data is required.

Hamilton Lake (Lake Rotoroa)

The data available on Hamilton Lake are a little different from that available on other NZLMP lakes. Monitoring of this lake commenced in 1992 as part of the NZLMP programme but was taken over in 1994 by the Hamilton City Council, which wished monitoring to continue on this lake because of civic need. Hamilton City Council has continued to support the monitoring of Hamilton Lake using the original NZLMP methodology, thus providing a long record of consistent data on the lake. These data show why it is necessary to examine data carefully, even when the first analysis of the data has given seemingly good results. Hamilton Lake (Figure 6.1) stratifies intermittently and no useful HVOD rates are obtainable for it. Correlations of data from four key variables for station HMRS against data for these variables from station HMRN for the same date and layer show that data from the two stations correlate with p-values < 0.001. The two stations give essentially equivalent data: if required for reasons of economy, only one station need be sampled.

Figure 6.2 shows temperature data from Hamilton Lake. The small-scale plot, Figure 6.2A, does not clearly show the low values observed in 1997, whereas these can easily be seen in Figure 6.2B, a plot of the residual data only. There was a change in the trend of the trophic level of this lake before and after 1994 and this is illustrated in some of the graphs shown in Figure 6.3. The Chla and SD trends are the same in the two periods of 1992–98 and 1994–98, Figure 6.3 (A–D). However, for TP, the trend in 1992–98 is seen to be declining, whereas that for 1994–98 is seen to be increasing, Figure 6.3 (E, F). Figure 6.3G shows a clear trend of declining TN values from 1992 to 1997 followed by a marked increase in TN in 1998.

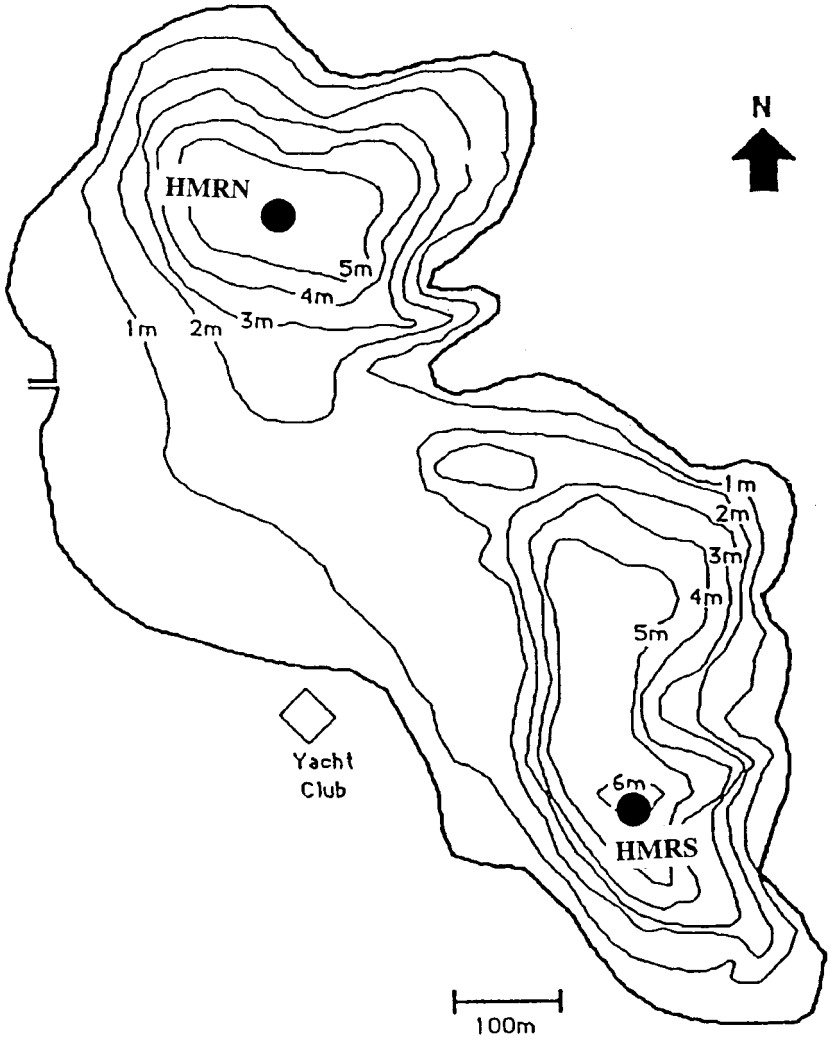


Figure 6.1: Hamilton Lake (Lake Rotoroa) showing the position of the two monitoring stations

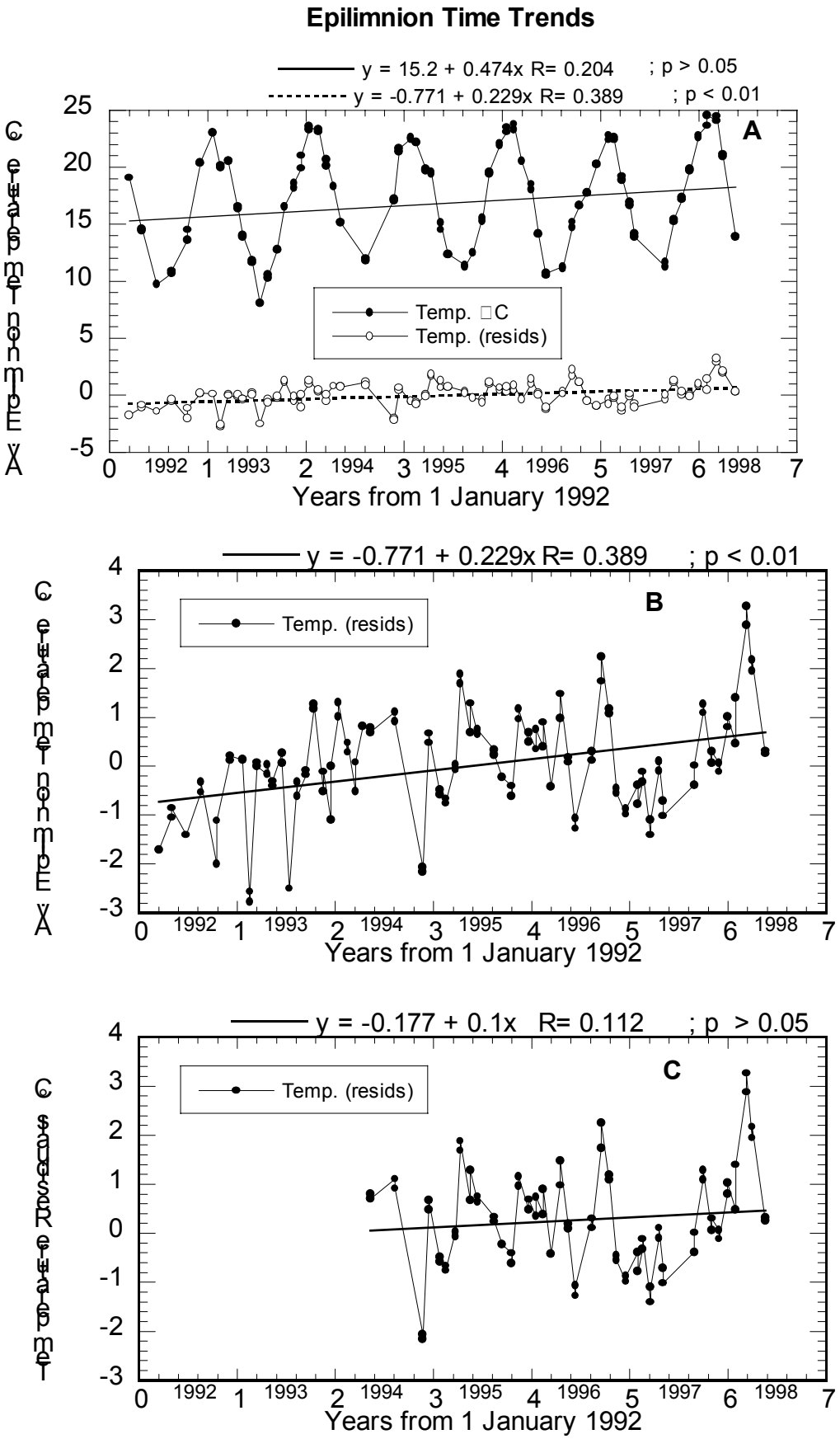


Figure 6.2: Graphs of Hamilton Lake data illustrating the improved ease of observing change in the pattern of data with larger scale plots

Table 6.1 shows the PAC values for 1992–98 demonstrating that there was a definite change in the PAC values during that time with a *p*-value of the PAC average of 0.03, but that there was no real change in the PAC values from 1994 to 1998 (*p*-value of average PAC is 0.34). The TLI data shown in Table 6.2 indicate that the TLI trend from 1992 to 1998 seems strong but the dashed line for the 1994-98 period represents a dubious relationship. The interpretation of these results would be that there was a definite improvement in the lake from 1992 to 1994 but since that time the improvement is doubtful. A further year's monitoring is needed to see if the 1999 TLI value is in the 4.6–4.7 range, indicating continued improvement, or in the 4.8–4.9 range, indicating that the lake has reached a new equilibrium state and is no longer improving.

Table 6.1: PAC values with their *p*-values for the two periods 1992–98 and 1994–98 for Hamilton Lake

Variable (units)	Annual change (slope = units year^{-1})	Apr 92 (or 94)–May 98 (average values)	PAC values (% year^{-1}) (slopes/av values)	*p*-values of regressions
1992–98 period				
Chla (mg m^{-3})	-2.02	16.3	-12.4	0.0001
Secchi depth (m)	0.07 x -1	1.1	-6.4	0.0001
TP (mg m^{-3})	-0.98	26.7	-3.7	0.002
TN (mg m^{-3})	-96.1	924	-10.3	0.0001
Average PAC value			-8.2	
p-value of PAC average			0.03	
1994–98 period				
Chla (mg m^{-3})	-1.92	12.7	-15	0.0026
Secchi depth (m)	0.08 x -1	1.4	-5.7	0.0003
TP (mg m^{-3})	1.05	25.7	4.1	0.046
TN (mg m^{-3})	(-0.41)	700	0	0.96
Average PAC value			-4.15	
p-value of PAC average			0.37	

Note: value in brackets is non-significant.

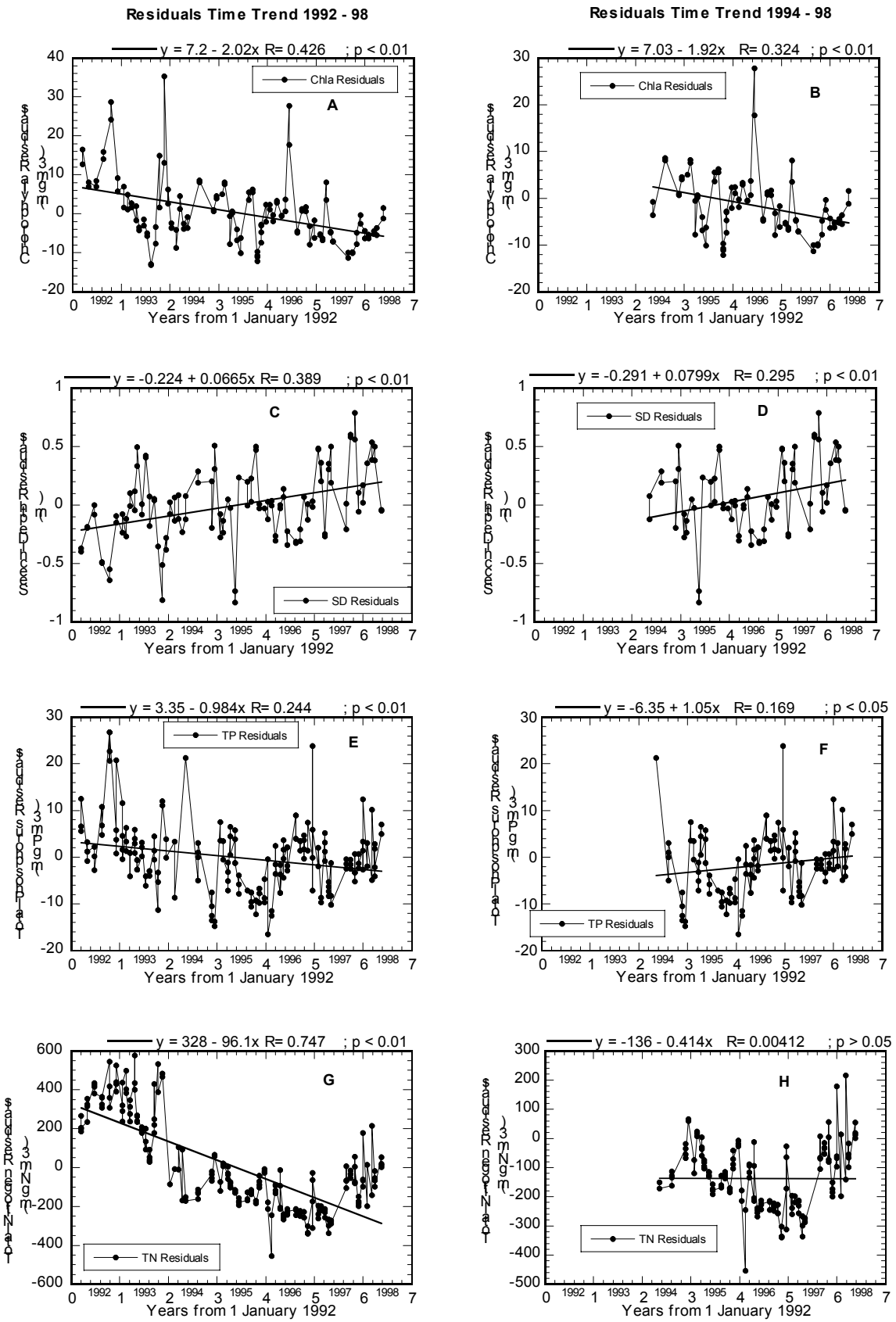


Figure 6.3: Plots of time trend residuals after deseasonalising observed data from Hamilton Lake from 1992 to 1998 and from 1994 to 1998

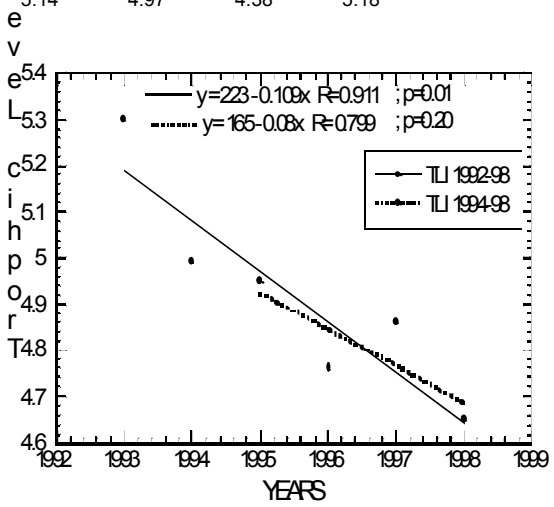
Table 6.2: Annual average values for the four key variables from Hamilton Lake with corresponding TLx and TLI values for the two periods 1992–1998 and 1994–98

Period	Chla (mg m^{-3})	SD (m)	TP (mg m^{-3})	TN (mg m^{-3})	TLc	TLs	TLp	TLn	TLI average	Std err TLI
Apr 92ĞMar 93	23.39	0.89	33.2	1216	5.70	5.20	4.64	5.68	5.30	0.25
Apr 93ĞMar 94	14.26	1.14	25.4	1107	5.15	4.94	4.31	5.55	4.99	0.26
Apr 94ĞMar 95	15.98	1.09	28.8	763	5.28	4.98	4.46	5.07	4.95	0.17
Apr 95ĞMar 96	12.35	1.09	21.1	722	4.99	4.98	4.07	4.99	4.76	0.23
Apr 96ĞMar 97	14.8	1.1	28.2	625.7	5.20	5.01	4.44	4.81	4.86	0.16
Apr 97ĞMar 98	8.20	1.40	26.0	718.0	4.54	4.73	4.33	4.99	4.65	0.14
Averages	14.84	1.11	27.11	858.45	5.14	4.97	4.38	5.18		

TLI 2-year value (1996Ğ1998) = 4.76; std error of 0.1

1992Ğ98 period
Av PAC value = -8% per year: *p* -value = 0.03
TLI trend = -0.11 units per year. Confirmed.

1994Ğ98 period
Av PAC value = -4% per year: *p* -value = 0.37
TLI trend = -0.08 units per year. The trend is rejected.



Notes:

The guide used in the PAC average *p*-value evaluation is:

< 0.1: definite change

0.1–0.2: probable change

0.2–0.3: possible change

> 0.3: no change

SE = standard error; av = average.

Lake Omapere

Lake Omapere is a shallow lake with a maximum depth of 2 m (Figure 6.4). Correlations of data from four key variables for station WHOW against data from station WHOE for the same variables, date and layer show that data from the two stations correlate with *p*-values < 0.001. The two stations give essentially equivalent data: if necessary for reasons of economy, only one station need be sampled.

The lake changed in character during the period of the NZLMP monitoring. At the start of the programme, the lake was virtually weedless; but in 1993 the weed started to grow back, with an extensive coverage existing by 1994 (Champion, 1995). The dramatic change in the lake is shown by the plots in Figure 6.5 (A–D). All four key variables show that the change occurred in September–October 1993. The change in SD is the most striking and the data on water level shows a decline at this time. A likely interpretation of what happened is that macrophyte regrowth had started in a minor way before September 1993, but in that month, a calm spell coincided with a drop in lake level. This clarified the water and greatly increased the area of the lake bottom in the photic zone. A consequent rapid establishment of *Egeria* occurred across the lake and this growth diminished resuspension of bottom materials, resulting in an increase in SD and decreased concentrations of Chla, TP and TN in the water.

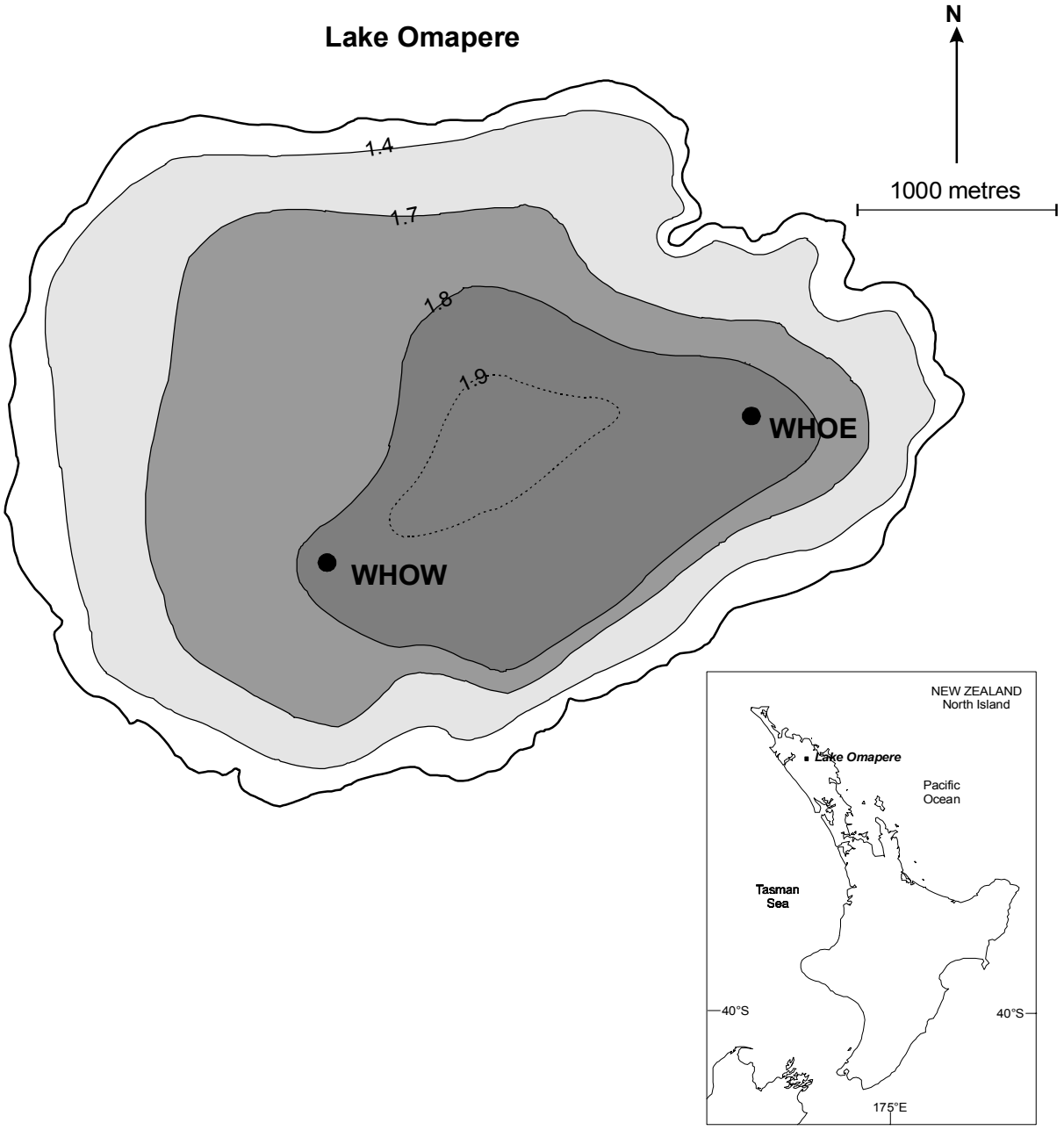


Figure 6.4: Lake Omapere showing the position of the sampling stations, WHOW and WHOE, both 1.8 m deep

Since the lake changed to a much lower set of concentration values in September 1993, data for the annualised plots were selected from that time to June 1996, Figure 6.5 (E-H). These plots show considerable scatter in all the variables with time of year; the only noticeable features are some spring growth in the phytoplankton (Figure 6.5E) and clearer water in the December–January period (Figure 6.5F). This means that monitoring frequency can be reduced if it is necessary to reduce sampling (and, hence, the quality of the data) in the interest of economy. Sampling is necessary in September, October, December and January but, other than these months and provided the lake remains in a stable state, sampling could be done bimonthly or even trimonthly after baseline monitoring of the lake had been completed.

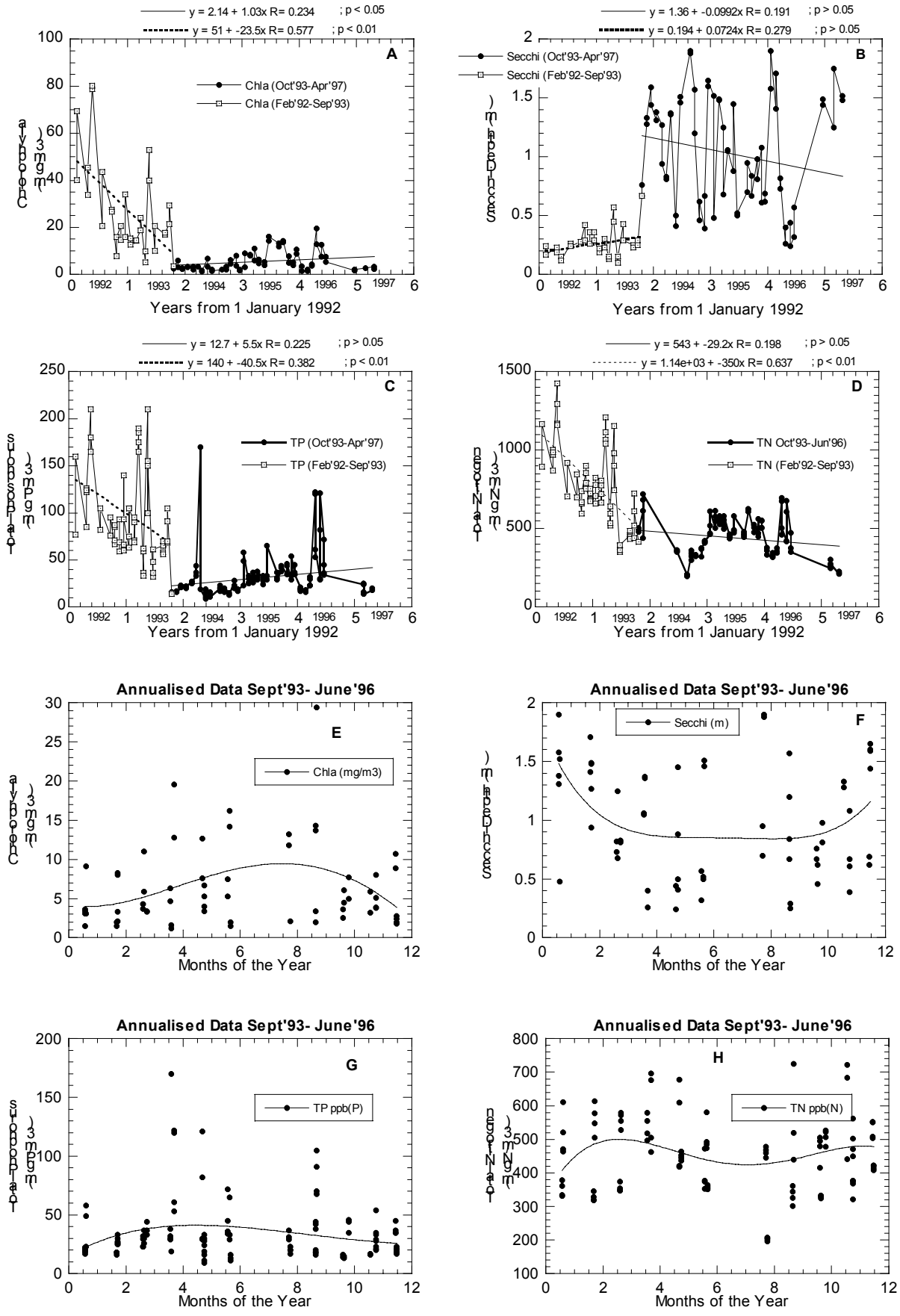


Figure 6.5: Plots of observed and annualised data for Lake Omapere key variables

Because the seasonal patterns are so weak in Lake Omapere, and processes in the lake appear to be dominated by the stirring up of bottom materials, the key variables were plotted against their corresponding TSS values out of interest: see Figure 6.6 (A, C, E, G). Strong correlations were found. High TSS concentrations are caused by strong winds stirring up the bottom materials, so these relationships mean that Lake Omapere is more strongly affected by the weather than by seasons. Thus residuals were obtained by making allowance for the TSS content of samples, as shown in Figure 6.6 (B, D, F, H). The residuals show very little trend with time, indicating that all the change seen in Lake Omapere was because the growth of the macrophytes decreased resuspension, not because of any decrease in nutrient loading. Nevertheless, the change occurred, so the magnitude of change in this instance was obtained from the slope of the lines fitted to the observed values, not from the slope of the lines fitted to the residual values.

The TLI and PAC values for Lake Omapere are shown in Table 6.3. The average PAC value of -33% year^{-1} (p-value = 0.02) means that there has been a definite and large improvement in the lake. The TLI time trend of -0.48 ± 0.12 units year^{-1} is in qualitative agreement with the PAC value and is confirmed as the rate of improvement of the lake over the years of observation. The lake has changed from being supertrophic (TLI of 5.97 ± 0.26) to eutrophic (TLI of 4.71 ± 0.13) over the four years of observation.

Table 6.3: PAC and TLI values for Lake Omapere

Lake Omapere	Chla (mg m^{-3})	SD (m)	TP (mg m^{-3})	TN (mg m^{-3})	Avs of PAC values and of TLx = TLI values	Standard error	p-value
Change (units year^{-1})	-6.57	0.19 x -1	-19.7	-117			
Av values 1992–96	13.4	0.77	53	573			
PAC (% year^{-1})	-49	-25	-37	-20	-33	6.3	0.02
TLx - 1992	6.09	6.45	6.1	5.23	5.97	0.26	
TLx - 1993	5.18	5.56	5.51	4.86	5.28	0.16	
TLx - 1994	3.59	4.97	4.31	4.08	4.24	0.29	
TLx - 1995	4.56	5.09	4.65	4.53	4.71	0.13	
Averages of TLc, TLs, TLp, TLn	4.86	5.52	5.14	4.68			
TLI 2-year av (1994–95) = 4.47 ± 0.16							
Time trend in TLI = -0.48 ± 0.12 units year^{-1}. Trend is confirmed.							

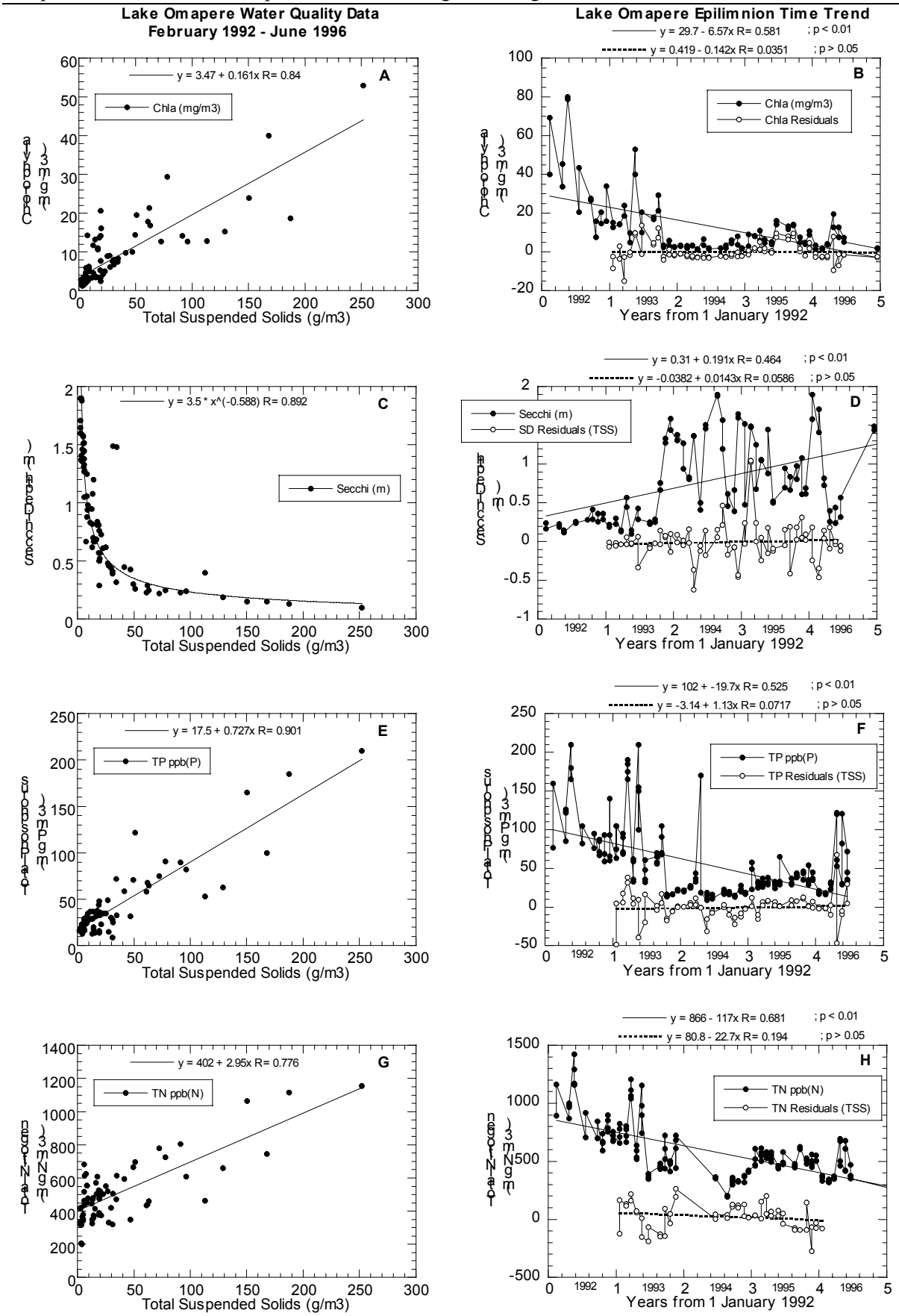


Figure 6.6: Observed values of key variables from Lake Omapere plotted against total suspended solids (TSS) and time trend plots of observed data and residuals derived from the TSS plots

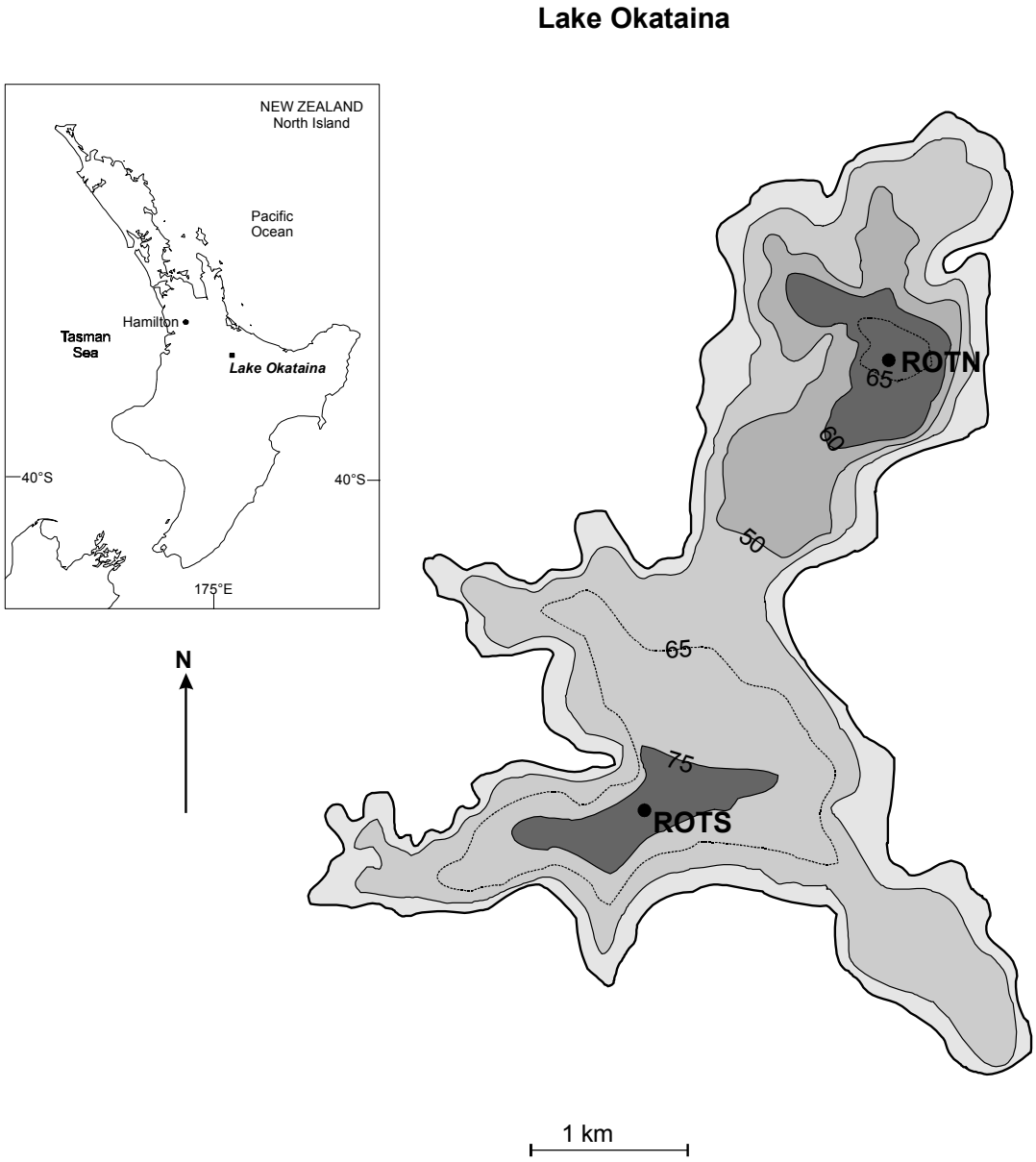


Figure 6.7: Lake Okataina showing the positions of the sampling stations: ROTN, chart depth 60 m, and RONE, chart depth 75 m

Lake Okataina

The bathymetry of Lake Okataina is shown in Figure 6.7. Correlations of data from the five key variables for station ROTN against data for these variables from station ROTS for the same date and layer show that data from the two stations correlate with *p*-values < 0.001. The two stations thus give essentially equivalent data: if necessary for reasons of economy, only one station need be sampled.

Figure 6.8 shows the annualised and time trend plots for the four epilimnion key variables. Figure 6.8 A–D) shows that Chla and SD demonstrate a strong seasonal pattern with a phytoplankton peak and an SD minimum in August. Figure 6.6 (E–H) illustrates some seasonal variation in TP and TN, with TN peaking before TP.

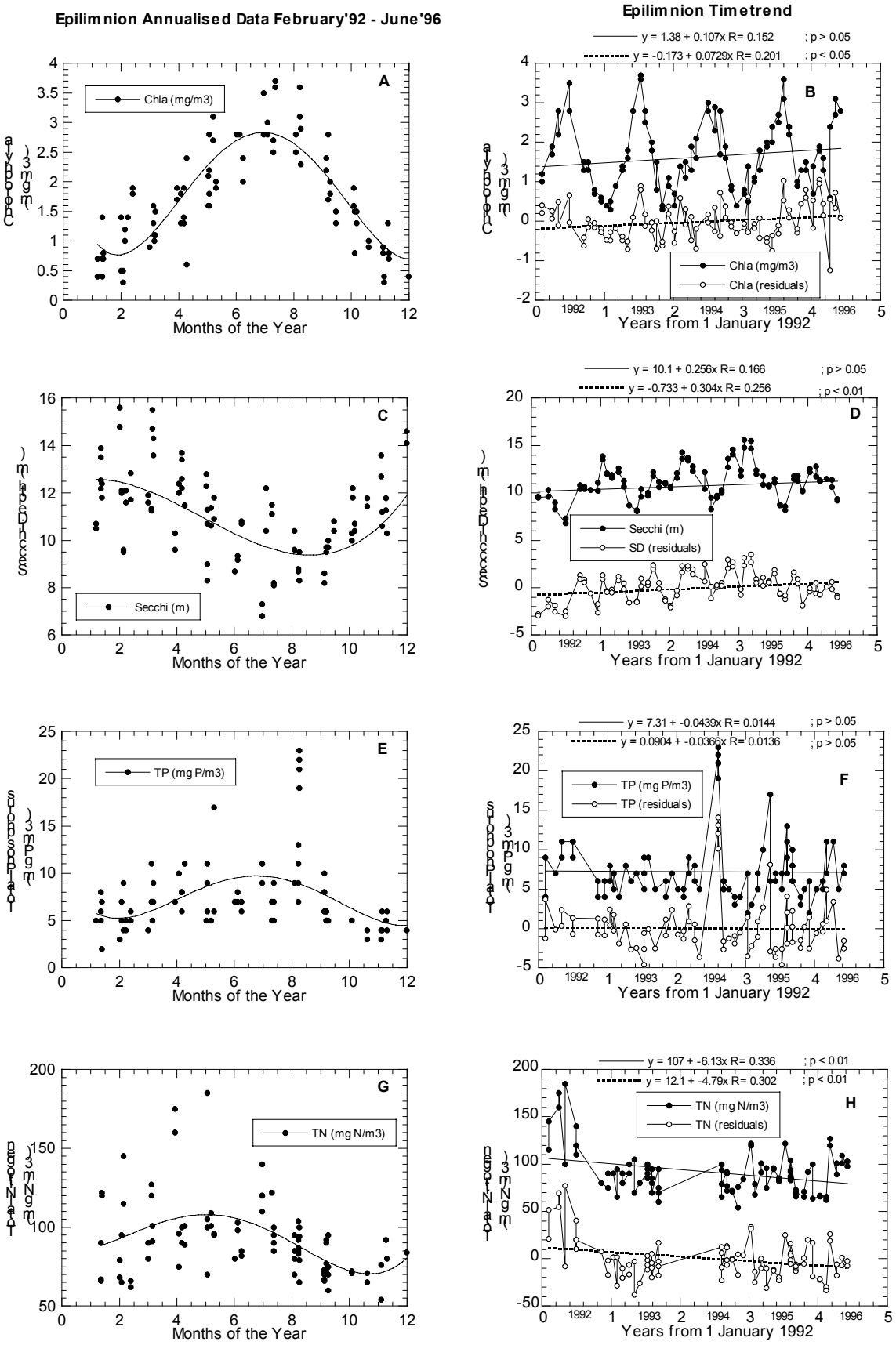


Figure 6.8: Plots of annualised and timetrend data for four key variables for Lake Okataina

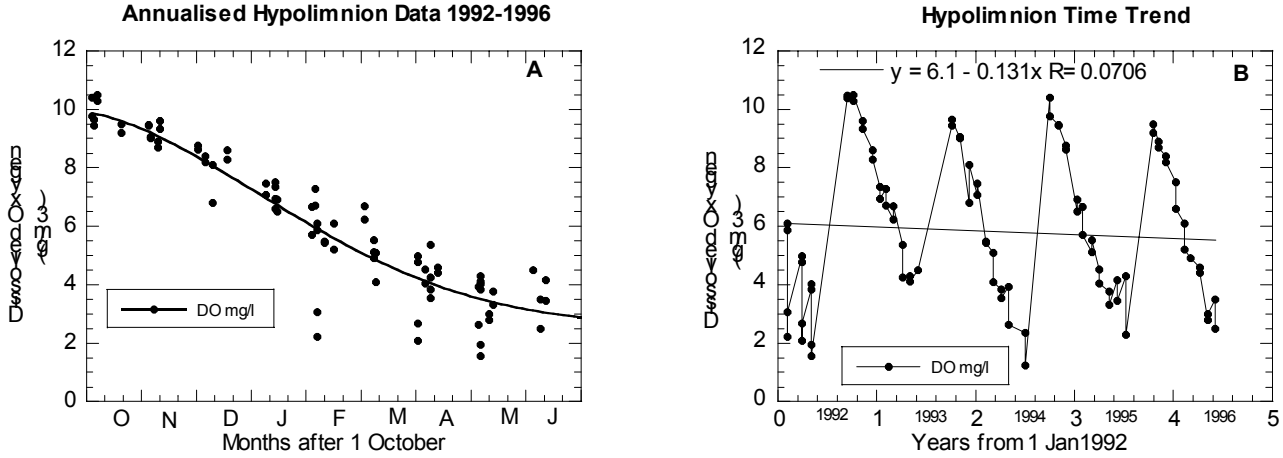


Figure 6.9: Plots of the Lake Okataina hypolimnetic DO observations

Plots of hypolimnetic DO in Figure 6.9 show Lake Okataina has an eight-month stratified period, during which time the average DO concentration declines steadily. Some of the individual measurements of near-bottom concentration reached close to 0.0 mg DO m^{-3} by the end of the season. The lake should be sampled in July and August to be sure of catching the Chla maximum and SD minimum, and October to catch the start of the HVOD measurement period. Other than these months, the lake could be sampled bimonthly if reduced sampling is necessary because all seasonal trends are smooth.

Table 6.4 shows the PAC values for five key variables (HVOD is included because Okataina is a stratified lake) and TLI values for the four TLI variables. The time trends for both indicators show no change with time, so it can be concluded that Lake Okataina was stable and unchanging from 1993 to 1996. The TLI value for the lake is 2.6 ± 0.1, indicating that Okataina is an oligotrophic lake. The TLn value is notably lower than the other TLx values indicating that the lake is nitrogen limited.

Table 6.4: PAC and TLI values for Lake Okataina

Lake Okataina	Chla (mg m^{-3})	SD (m)	TP (mg m^{-3})	TN (mg m^{-3})	HVOD (mg DO m^{-3} day^{-1})	Avs of PAC values and of TLx = TLI values	Std error	*p*-values
Change (units $year^{-1}$)	-0.08	0.03 x -1	(-0.037)	-4.8	(-0.02)			
Av values (1992–96)	1.63	10.7	7.2	91	31.7			
PAC (% $year^{-1}$)	4.7	-0.3	(+0.5)=0	-5.3	(0)=0	-0.14	1.67	0.93
TLx - 1993	2.49	2.48	2.66	2.32		2.49	0.07	
TLx - 1994	2.80	2.43	2.55	2.17		2.49	0.13	
TLx - 1995	2.74	2.35	2.89	2.20		2.55	0.16	
TLx - 1996	2.97	2.52	2.69	2.24		2.60	0.15	
Avs of TLc, TLs, TLp, TLn	2.75	2.44	2.70	2.23		2.53	0.24	0.5
TLI 2-year av (1995–96) = 2.6 ± 0.1 TLI units								
Time trend in TLI = 0.04 ± 0.05 levels $year^{-1}$.								

Note: Non-significant changes are bracketed.

6.2 Case study of an ecological report on a lake

Lake Okareka will be used to provide the example of an ecological report on a lake. The water quality component of this section will also provide a further case study from the NZLMP monitoring data. The bathymetry of the lake is shown in Figure 6.10. Correlations of data from the five key variables for station HMRS against data for these variables from station HMRN for the same date and layer show that data from the two stations correlate with p-values < 0.001. The two stations give essentially equivalent data: if necessary for economic reasons, only one station need be sampled.

Lake Okareka and its catchment

Physical information on Lake Okareka and its catchment is shown in Table 6.5.

Lake Okareka occupies a small catchment with a dammed section of the Okareka embayment of the Haroharo Caldera. Steep caldera walls and surrounding slopes provide a high degree of containment for the lake and, together with a low-lying area, create an intimate landscape. The predominant land use is residential settlement, agriculture and scenic reserve. The valley originally drained into Lake Tarawera but was truncated by lava associated with the Te Rere eruptive episode. Lake Okareka is relatively shallow (mean depth < 20 m) and just in the mesotrophic range.

Pasture has been the dominant land cover during this century and has changed little since 1978 (Donald, 1997). However, in the last 20 years the area of indigenous vegetation has reduced by approximately 6% through increases in urban and exotic forestry development. There are now numerous homes around the lake, many of them occupied by permanent residents and covering about 3% of the catchment area. These homes currently discharge their household wastes into septic tanks which overflow into the catchment soils around the lake. After Lake Rotorua, Lake Okareka has the second-highest density of human population (increasing markedly in summer) of all the Rotorua lake margins.

There is no river input directly into the lake, so the lake must receive its water from groundwater seepage, catchment runoff and direct rainfall. There is a stream flowing from the lake into Lake Tarawera. This stream has a water quality which is much the same as that of Lake Okareka, except that enterococci numbers in the stream can increase to over 100 per 100 ml after rain. This is thought to be the result of runoff from adjacent pasture. At the present time, the lake level is regulated by a valve controlling water discharge through a channelled and piped stream that discharges into Waitangi Bay (Lake Tarawera) via Waitangi Spring. Figure 6.11 shows that the lake level has risen from 1993 to 1996 by 0.24 m per year. The higher lake levels have been causing the residents concern and there is now a report discussing the problem (Wallace, 1999).

Table 6.5: Summary of lake dimensions and land cover associated with Lakes Okareka

Dimensions		Land cover (%)	1978	1996
Catchment area (ha)	1,865	Indigenous forest and scrub	44.4	38.1
Lake area (ha)	334	Exotic forest	0	2.6
Maximum depth (m)	33.5	Pasture	55.6	55.8
Mean depth	20	Wetlands	0	0
Long axis (km)	2.8	Urban	0	2.9
Altitude (m)	355			
Age (x 1000 years)	19			

Source: Donald, 1997.

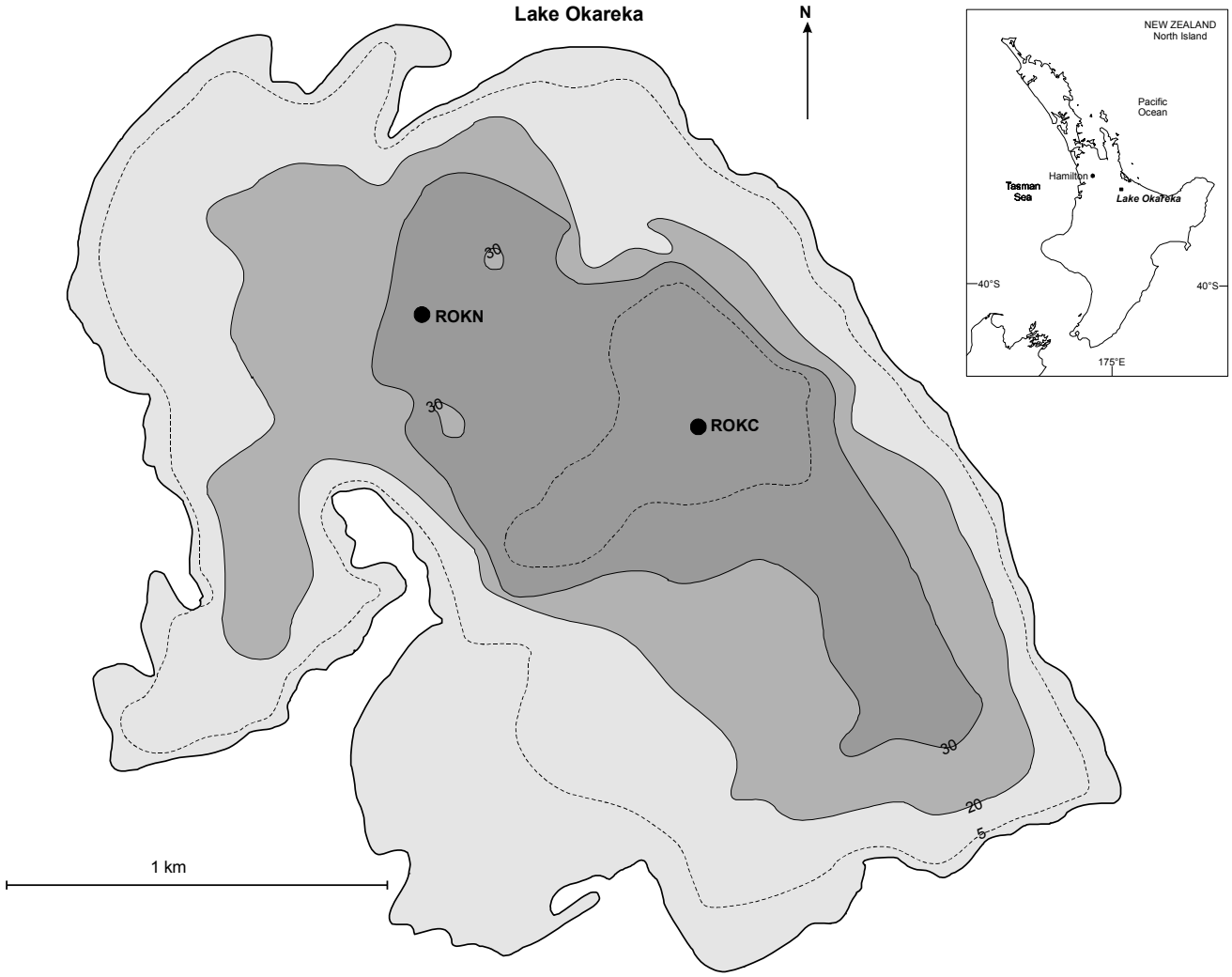


Figure 6.10: Lake Okareka showing the positions of the sampling stations: ROKN, chart depth 30 m, and ROKC, chart depth 33.5 m

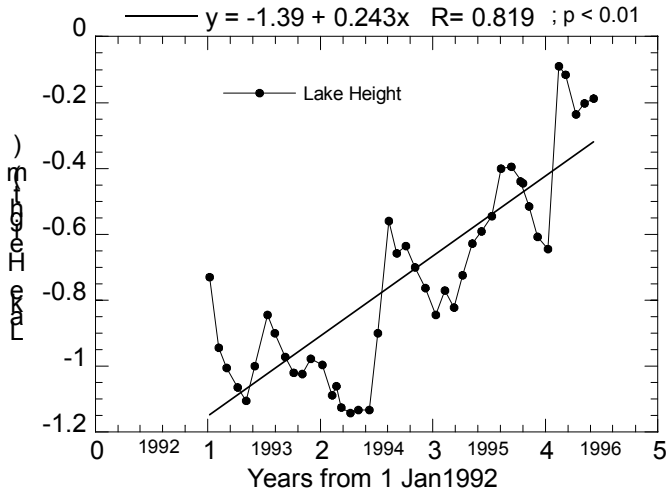


Figure 6.11: Change in lake level in Lake Okareka from 1992 to 1996

Water quality

Lake Okareka has generally had good water quality, which is much enjoyed by visitors and the people who live around the lake. The water quality of this lake should be preserved.

The plots and tables which are part of a normal analysis of NZLMP data are shown in Figures 6.12 to 6.17 and Tables 6.6 and 6.7. A fairly lengthy commentary could be written on the chemical limnology of the lake if all the features shown in these graphs and tables of information on Lake Okareka were discussed. This commentary is available in the report on the NZLMP results (Burns and Rutherford, 1998), so only the items pertinent to possible change in the trophic level of Lake Okareka will be described here (not always in sequence of the illustrated data).

Figure 6.12 (A, B) shows that the average temperature of Lake Okareka has increased steadily by 0.35°C $year^{-1}$ or 1.4°C over the four years of monitoring – a considerable increase in the average temperature of a lake. Figure 6.12 (C, D) shows that the hypolimnion temperature in 1994–95 was significantly higher than the other years. Plots of vertical profiles from June of different years are presented in Figure 6.12 (E, F) and show that stratification can last a month longer some years than other years.

Figures 6.12 (G, H), 6.13 and 6.14 show the hypolimnetic DO conditions that prevailed in Lake Okareka over the four years of monitoring. The HVOD rate (Figure 6.14) shows a non-significant decrease with time in both the observed and the temperature-adjusted rate. The highest HVOD rates were measured in the 1994–95 stratified season (Table 6.6) and the lake was still stratified in June 1995, so there was probably significant nutrient release in that month. Figure 6.16A shows some high concentrations of TP at the end of the 1992 and 1993 stratification periods in May and June in the hypolimnion waters; it shows further high values in 1995 and a very high value in June 1996, when sampling ceased. These high values of TP indicate occurrence of anoxic regeneration of phosphorus. Figure 6.16B shows high hypolimnetic values of TN in 1995 and 1996. Figure 6.17D shows increased hypolimnetic turbidity with time, which could be related to increasing anoxic conditions. Further, Figure 6.15 (B, D) show that the phytoplankton responded to the high concentrations of nutrients in the anoxic hypolimnetic water when it was mixed upwards by producing high Chla and low SD values in mid-1995 and mid-1996. Epilimnetic TP was very high in August and September 1994 and August 1995 (Figure 6.15F) as a result of earlier anoxic releases of nutrients into the anoxic hypolimnion waters and, subsequently, into the isothermal waters of the lake.

The PAC values, Table 6.7, show some contradictory results: Chla, SD and TP indicate increasing eutrophy whereas the HVOD rates show a decline with time (even if they are non-significant). This contradiction can be resolved by considering that, in Lake Okareka, it is not the HVOD rates but the observed DO concentrations at the end of the stratified season that are all-important, because a longer stratified season can result in anoxic conditions even with lower HVOD rates. Further, the length of the stratified season is probably determined by the summer and autumn temperatures. If they are high, the stratification stability is strong and stratification can last well into June, with subsequent anoxic regeneration of nutrients. This sequence of events has probably happened in Lake Okareka, where a significant temperature increase with time has been observed in parallel with Chla and TP increases.

With global warming apparently an established phenomenon at present, higher lake surface temperatures could lead to longer periods of stratification, and hence to increasingly large anoxically regenerated internal loads of nutrients. If this is so, external inputs of nutrients will have to be diminished to counteract the effects of the increased internal loading resulting indirectly from warmer lake temperatures. External nutrient loadings to Lake Okareka have been examined by Donovan and Don (1991), who found that nutrient runoff from pastures caused the largest nutrient loading to the lake, followed by septic tank leachate and then urban runoff.

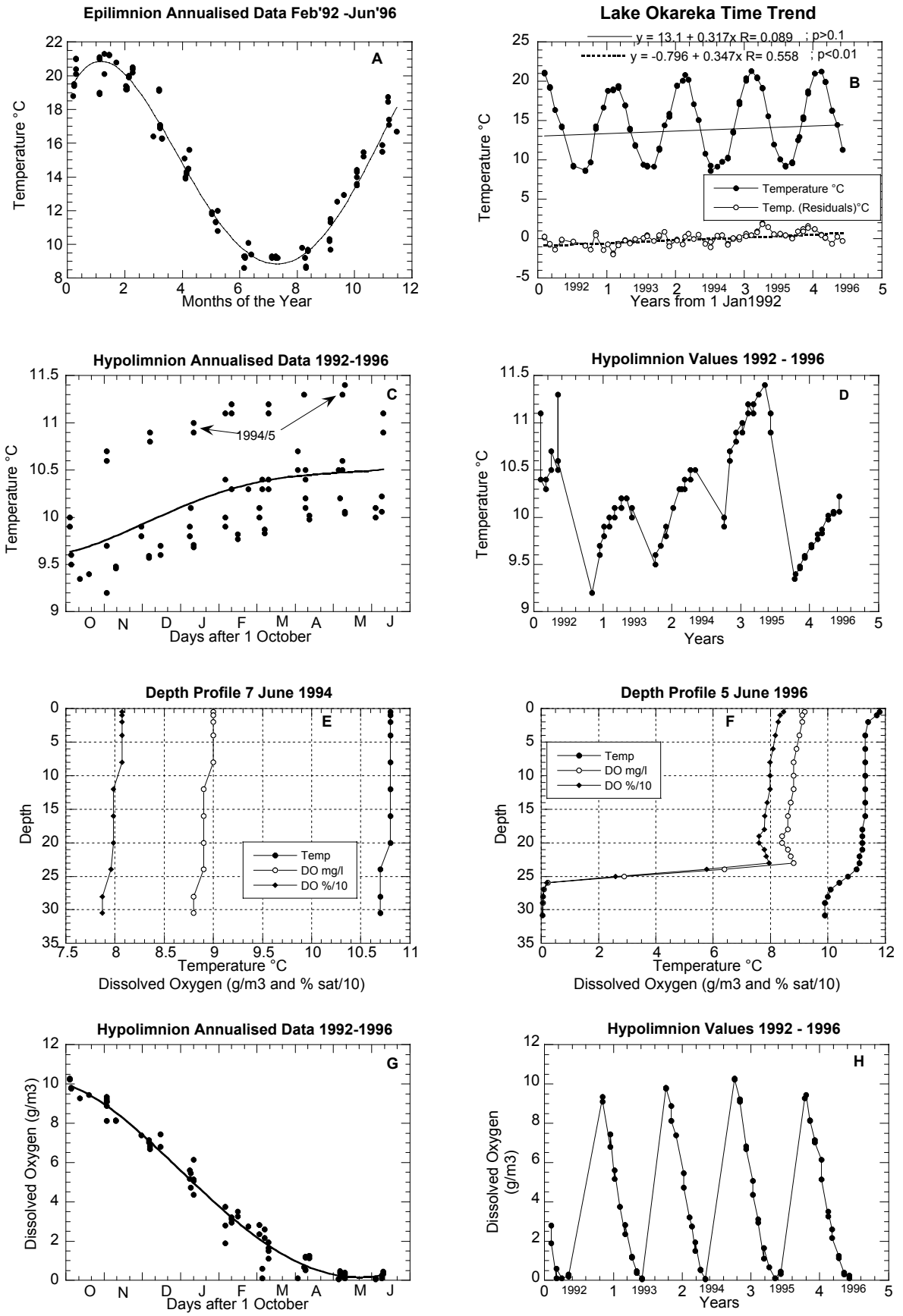


Figure 6.12: Plots of Lake Okareka temperature and DO observations

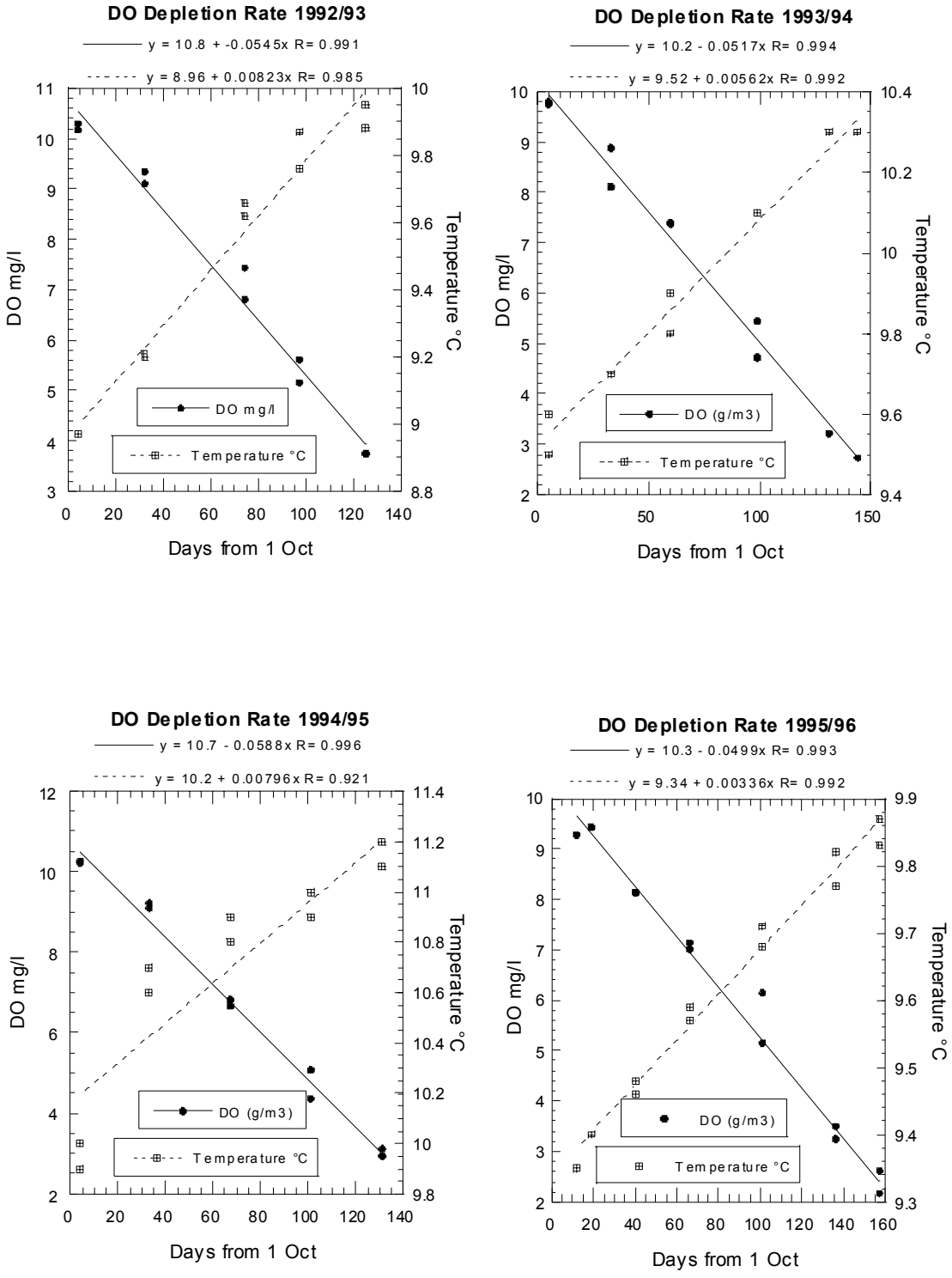


Figure 6.13: HVOD plots for Lake Okareka

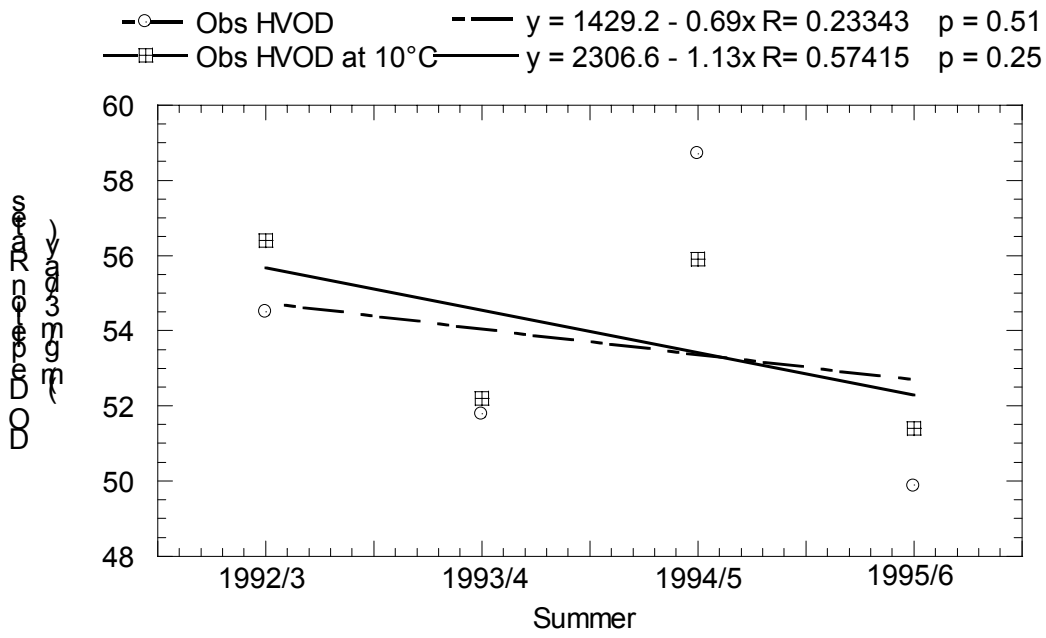


Figure 6.14: HVOD rates for Lake Okareka 1992–96

Table 6.6: Observed and temperature adjusted HVOD rates for Lake Okareka

Summer	Average temperature (¡C)	Observed DO depletion rate (mg m^{-3} day^{-1})	Observed rate corrected to 10.0¡C (mg m^{-3} day^{-1})
1992/93	9.51	54.5	56.4
1993/94	9.9	51.7	52.2
1994/95	10.7	58.8	55.9
1995/96	9.58	49.9	51.4
Averages		53.7	54.0

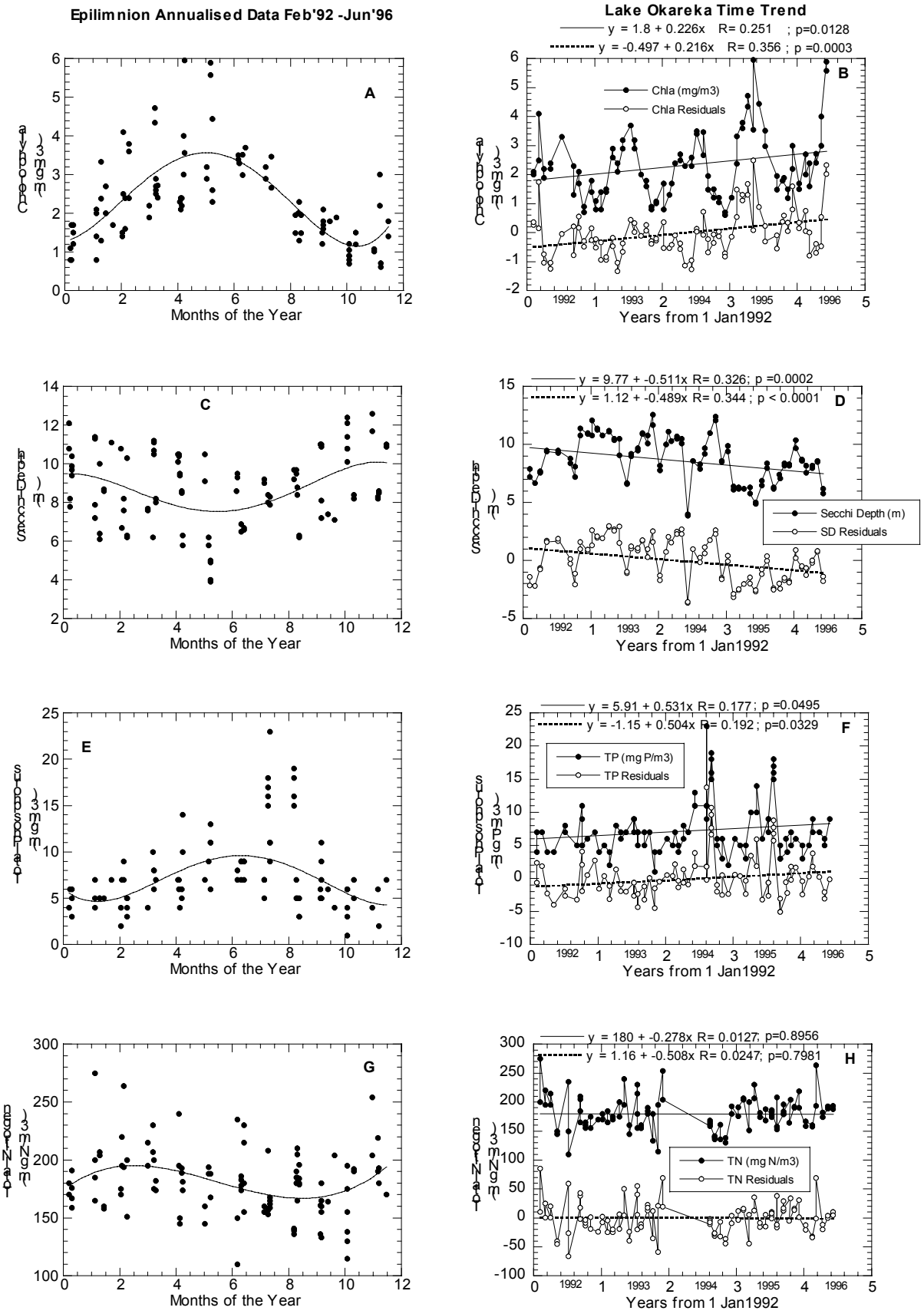


Figure 6.15: Annualised and residual plots for the Lake Okareka epilimnion key variables

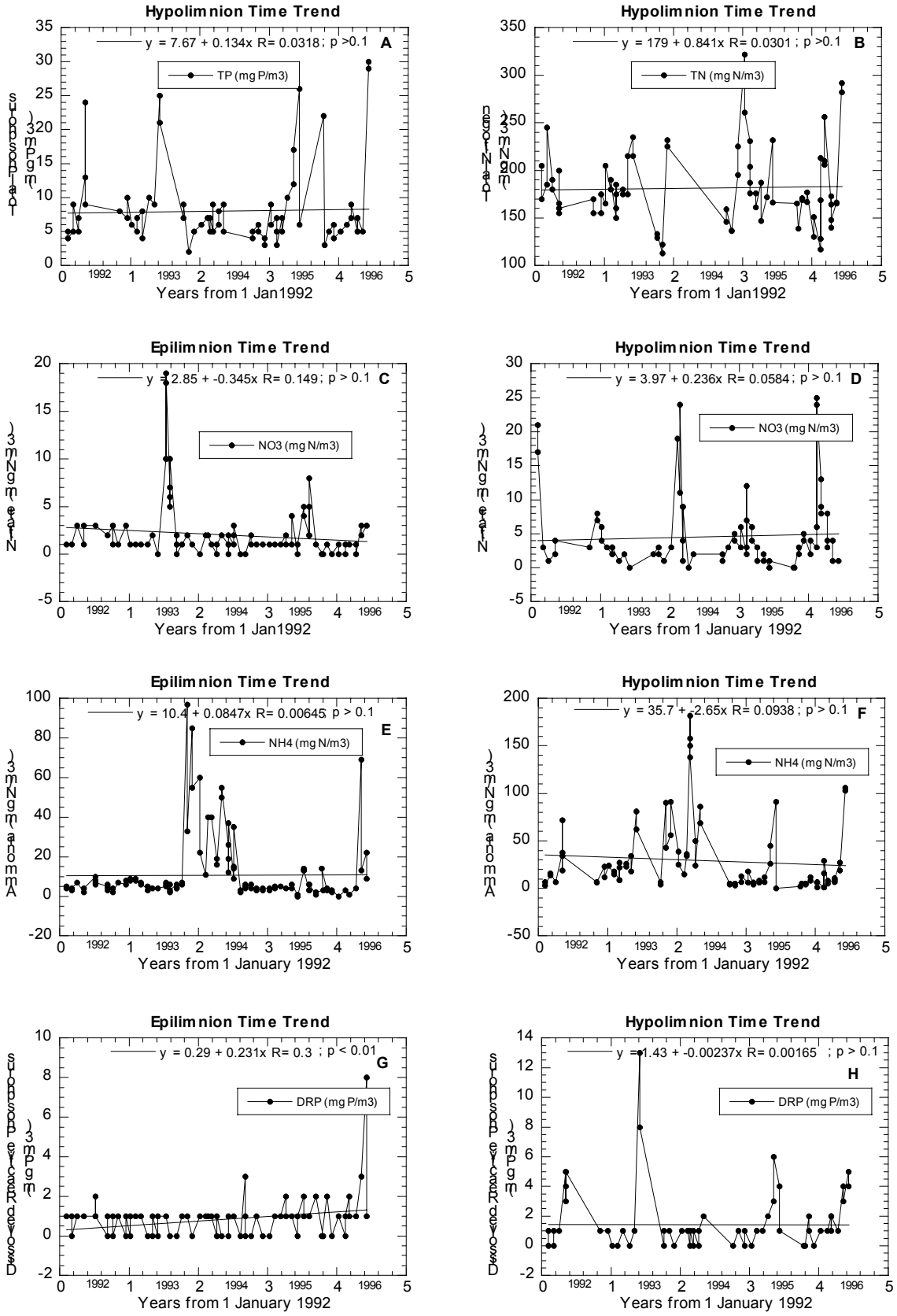


Figure 6.16: Plots of observed values for Lake Okareka epilimnetic and hypolimnetic variables

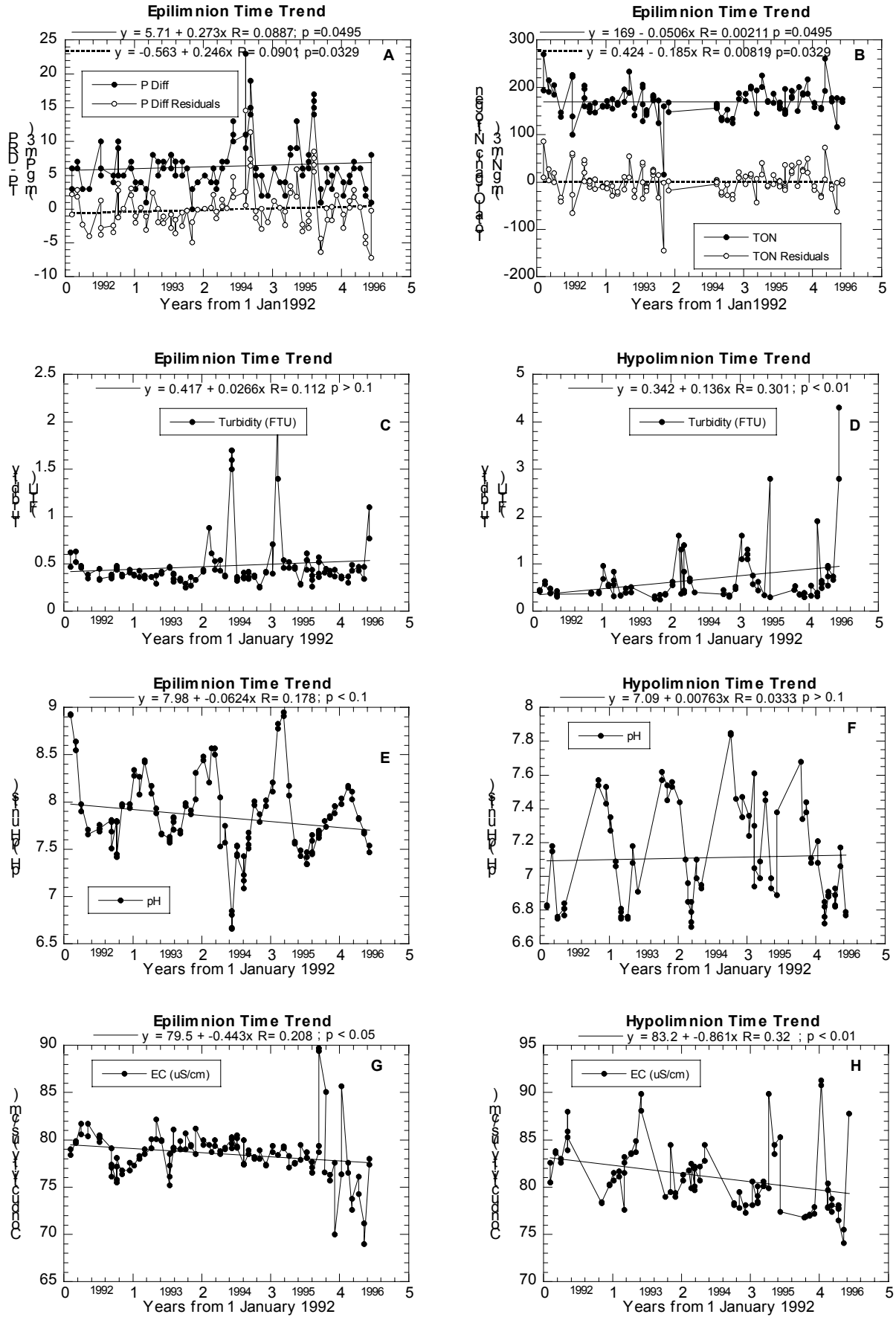


Figure 6.17: Plots of observed values for Lake Okareka epilimnetic and hypolimnetic variables

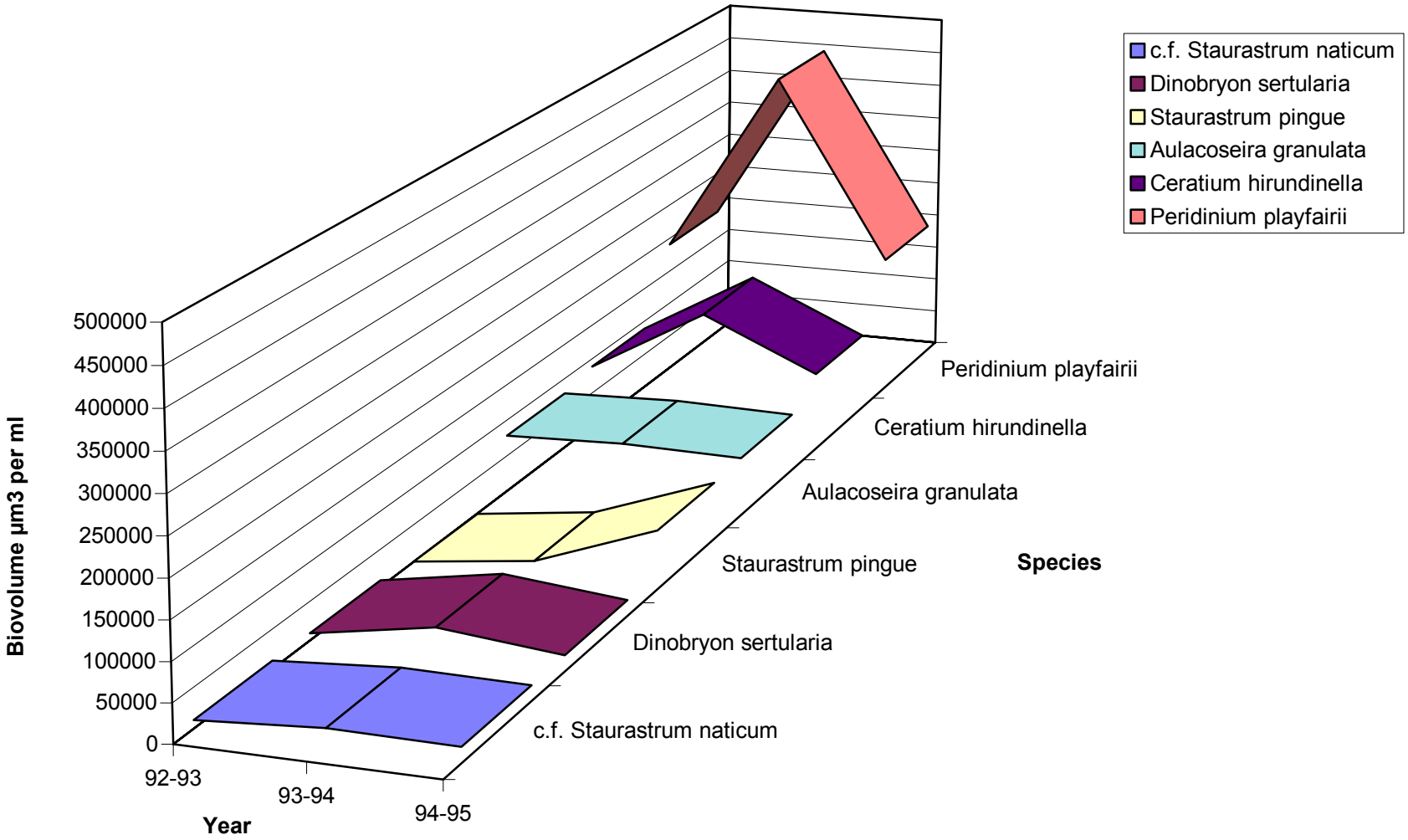


Figure 6.18: Mean phytoplankton volumes for dominant species, Lake Okareka, 1992–95

The TLI value for Lake Okareka (1994–95) is 3.0 ± 0.1 and is rising at the rate of 0.13 ± 0.05 year^{-1} (Table 6.7). The interpretation of the PAC result shown in Table 6.7 – an average increase of 4.5% year^{-1} with a *p*-value of 0.11 – is that the lake is probably deteriorating. The *p*-value > 0.1 means that no definite conclusion can be reached on the basis of the NZLMP data. However, Environment B·O·P (EBOP) has been monitoring Lake Okareka since 1998 and its data have been examined (Burns, 1999) to see whether the NZLMP observation of declining lake water quality has been maintained after NZLMP sampling stopped in June 1996. Results in Table 6.8 show similar TLI levels calculated for Lake Okareka from EBOP and NZLMP data in 1994–95; in addition, the EBOP data show that the TLI of the lake increased from an average value of 3.20 ± 0.14 in 1987–94 to 3.48 ± 0.32 TLI units in 1995–98. The EBOP information confirms that Lake Okareka is becoming increasingly eutrophied, probably at the TLI time trend value of 0.13 ± 0.05 TLI units per year^{-1}.

The annualised plots, Figures 6.12G and 6.15 (A, C, E, G) need to be examined to determine the months necessary for adequate sampling. Figure 6.12G indicates that the lake should be sampled monthly from October to July to observe the depletion of DO and any subsequent nutrient regeneration during the anoxic period; and because TP maxima occur during July and August, the lake should also be sampled during these months. Thus, seemingly, September is the only non-critical month and it could be omitted from a sampling plan. However, given the changing nature of Lake Okareka, it would be wise to sample this lake every month.

Perhaps one of the most telling indications of change of trophic condition is that the TLp (2.69) and TLn (3.15) values show that Lake Okereka is phosphorus limited (Table 6.7), and it is the only Rotorua District lake to exhibit this condition. This situation could arise from drainage from pastures and septic tanks around the lake loading more soluble nitrogen into the lake than soluble phosphorus. From 1992 to 1996 the TLI of the lake has increased from values of 2.8 ± 0.2 to 3.0 ± 0.1, so the lake is changing from oligotrophic to mesotrophic. With the lake approaching the condition of anoxic regeneration of nutrients each year and experiencing longer periods of stratification from the warming of the lake waters, steps should be taken to restrict the external input of nutrients. This can be done by planting riparian strips to diminish runoff from pastures and by installing sewage reticulation to diminish septic tank leachate into the lake.

Table 6.7: PAC and TLI values for Lake Okareka

Lake Okareka	Chla (mg m^{-3})	SD (m)	TP (mg m^{-3})	TN (mg m^{-3})	HVOD (mg DO m^{-3} day^{-1})	Avs of PAC values and of TLx = TLI values	Std error	*p*-values
Change (units year^{-1})	0.22	-0.49 x -1	0.50	(-0.51)	(-1.13)			
Av values (1992–96)	2.3	8.6	7.1	179	54			
PAC (% year^{-1})	9.4	5.7	7.1	(-0.3)=0	(-2.1)=0	4.5	1.93	0.11
TLx - 1992	2.89	2.56	2.50	3.14		2.77	0.15	
TLx - 1993	2.93	2.63	2.55	3.14		2.81	0.14	
TLx - 1994	3.30	2.80	2.98	3.11		3.05	0.11	
TLx - 1995	3.27	2.88	2.75	3.21		3.02	0.13	
Avs of TLc, TLs, TLp, TLn	3.10	2.72	2.69	3.15		2.91	0.27	
TLI 2-year av (1994–95) = 3.0 ± 0.1 TLI units								
Time trend in TLI = 0.13 ± 0.05 levels year^{-1}.								

Note: Non-significant changes are bracketed.

Table 6.8: Comparison of TLI values calculated from NZLMP and EBOP data for Lake Okareka

Data source	Period	Chla ($mg\ m^{-3}$)	SD (m)	TP ($mg\ m^{-3}$)	TN ($mg\ m^{-3}$)	TLc	TLs	TLp	TLn	TLI avs (TLI units)	Std error
NZLMP	1993 and 1995	2.43	8.49	6.8	183	3.20	2.76	2.64	3.20	2.95	±0.15
EBOP	1987–94	3.13	6.85	8.4	215	3.48	3.02	2.91	3.41	3.20	±0.14
EBOP	1995–98	6.73	5.69	7.8	241	4.32	3.23	2.81	3.56	3.48	±0.32

Bathing suitability

EBOP has monitored enterococci numbers in waters of Lake Okareka's bathing beaches on a two-year cycle since 1991. Data collected showed that the lake complied with regulations in 1991, 1993 and 1995 (Deely and McIntosh, 1998). Ministry of Health guidelines specify that for safe bathing, the number of enterococci allowed in lakes and rivers must not exceed 33 per 100 ml in a minimum of five samples collected during the bathing season: this guideline has been exceeded only in 1998. The high enterococci median of 100 per 100 ml measured at the jetty site in 1998 was thought to reflect either heavy bathing or septic-tank seepage**.** There are some low-lying areas of shoreline where the roads are close to the lake and near the Acacia Bay jetty. These areas are sometimes flooded during periods of heavy rain. Water samples taken from the ponded areas that result at these times, can show high levels of bacterial contamination (Deely, 1998).

Phytoplankton and macrophytes

Figure 6.18 shows the average annual biomass of the six dominant phytoplankton species in Lake Okareka from 1992 to 1995. *Peridinium playfairii* appeared to be the only major species undergoing significant year-to-year change: the other species are relatively stable. A comparison of reported phytoplankton observations on Lake Okareka from 1959 to 1993 was not able to discern any major change in species over that time (Burns *et al*, 1997).

Figure 6.19 shows the results of a macrophyte survey carried out by Clayton and Wells (1989). Emergent shoreline vegetation covers 20 percent of the lake shore, principally in the sheltered bays. The main native emergents (*Baumea articulata,* raupo and *Eleocharis sphacelata*) grow to 2 m in height. There is a high frequency of short, shallow-water plant associations. These exist around half the shoreline in areas with moderate exposure to wind and wave action.

Lagarosiphon is dominant in water depths of 2–6 m where it forms single-species beds. In 1988 the *Lagarosiphon* in Lake Okareka was found to be 5 m tall, the tallest recorded in any of the Rotorua lakes. The steep shoreline gradients have, however, confined *Lagarosiphon* beds to a narrow band, totalling about 40 ha. Below the *Lagarosiphon* beds are the *Elodea* beds. These are usually single-species beds with plants up to 3.5 m tall in water depths of 6–9 m.

The native characeans dominate the zone between 7 m and 12 m, below the oxygen weeds. Nine characean species are present, the highest number recorded for any of the Rotorua lakes. The submerged vegetation in the large shallow embayment in the southwest sector of the lake varied from the rest of the lake. In this area, an extensive shallow water characean meadow occupied water depths from 0.5 m to 4 m, above the *Lagarosiphon* weedbeds (Froude and Richmond, 1990).

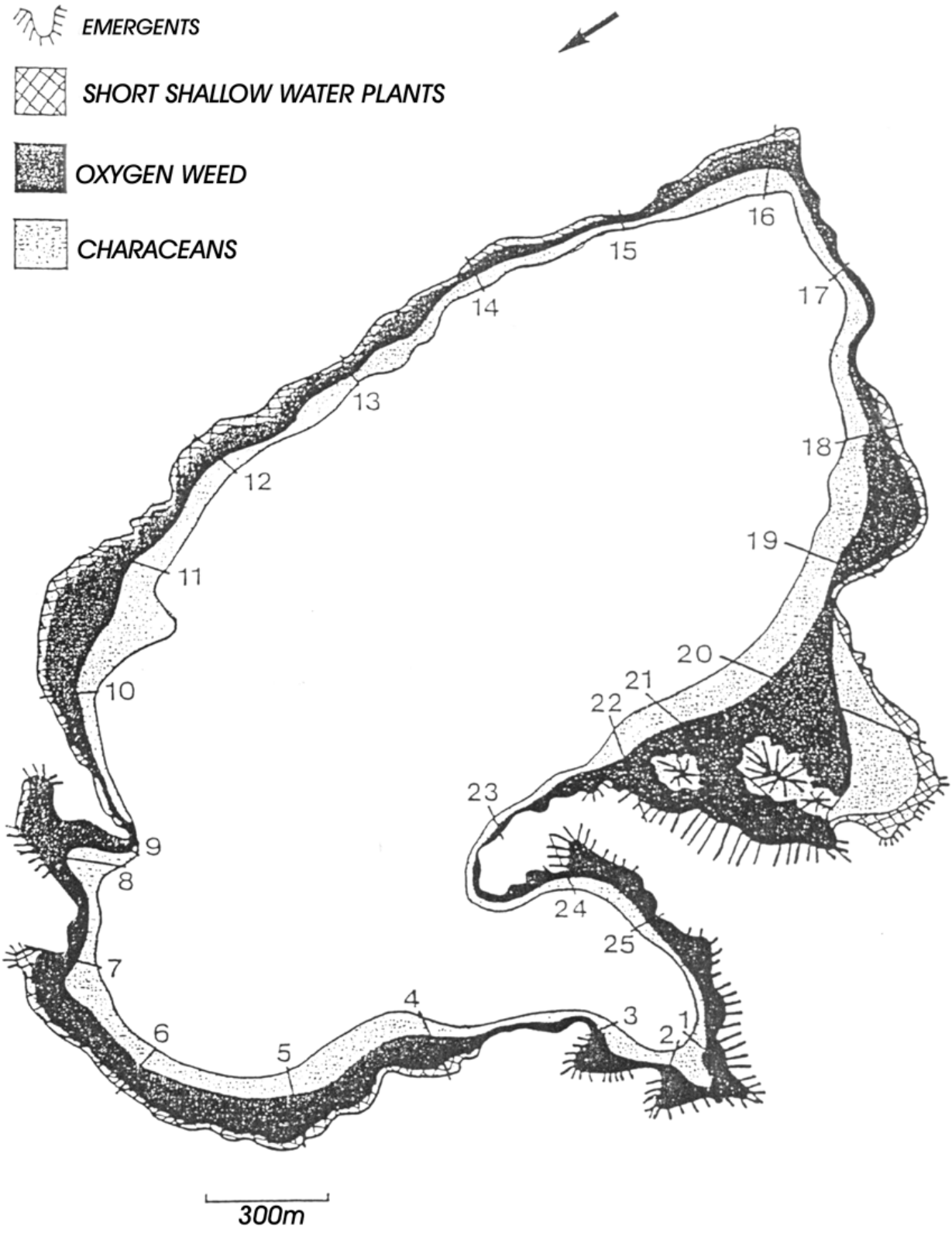


Figure 6.19: Map of the distribution of macrophyte beds in Lake Okareka in November 1988 (Source: Clayton and Wells, 1989)

Sediments

Bloomkvist and Lundsteldt (1995) measured nutrient and metal concentrations in sediments from deep accumulation deposits of the 13 major Rotorua lakes. Lake Okareka had the third-to-lowest concentration of TP in the sediments of the Rotorua lakes (1.1 g P kg^{-1}) and was relatively low in TKN at less than 6 g N kg^{-1}. Lake Okareka sediments contained about 90 mg NH_4-N kg^{-1}. The sediments were relatively rich in iron, manganese, arsenic and mercury, elements that are usually in high concentration in geothermal waters. Concentrations of the metals, cadmium, chrome, copper, lead and zinc that are not normally associated with geothermal activity, were very low in concentration in the sediments of the lake.

The sediments were also sampled to investigate the levels of chlorophylls and carotenoids in them (Gall and Downes, 1997). The oxidised layer on the surface of the sediments was found to be from 0.5 cm to 1.5 cm, and the sedimentation rate 0.03 ± 0.003 g cm^{-2} $year^{-1}$. The chlorophylls and carotenoids were extracted from different layers of sediment and the layers were dated. Increases in these pigments were first observed in the sediments laid down in the early 1940s when traces of the pigments associated with cyanobacteria and cryptophytes were detected. The rate of increase in total pigments has proceeded at a linear rate since that time.

Wildlife

The Lake Okareka fishery is of regional importance with the lake's mesotrophic status generally providing ideal conditions for fish production. However, only limited spawning occurs on gravelly lake margins and this is supplemented with an annual liberation of yearling rainbow trout (Department of Lands and Survey, 1986). Most of the common North Island terrestrial bird species are found in the area around the lake. Many of the endemic aquatic species such as the New Zealand shoveler, scaup, paradise shelduck and dabchick are found, as are the more general species such as shags, coots, grebes, terns, crakes, swans, herons and ducks (Department of Lands and Survey, 1986).

Conclusions on the general state Lake Okareka

Lake Okareka appears to be changing slowly from an oligotrophic lake with TLI values in the 'high twos' to being a mesotrophic lake with TLI values in the 'low threes'. The lake is still in relatively good condition in all aspects except that the hypolimnetic DO values drop to zero by the end of the stratified season, resulting in occasional anoxic regeneration of nutrients. Loading from this internal source could become greater as the average temperature of the lake increases with global warming. The other possible cause of increased nutrient input could be from runoff from nearby pastures and seepage from septic tanks. The observed slowly increasing eutrophication is particularly worrisome because, if the lake deteriorates further and substantial anoxic regeneration of nutrients from the sediments occurs, its subsequent degradation will be rapid. The only possible remedial action that can be taken is to decrease the external input of nutrients.

6.3 Assessment of reservoir data

Lake Rotorangi is a reservoir created from damming the Patea River in Taranaki. The lake is riverine in shape being 46 km long with an average width of 130 m and average depth of 28 m. Three sampling stations were created on the lake about 20 km from each other and four samples per year were collected from these stations. Station L1 is sited at the head of the lake at a depth of 10 m and a lake width of less than 100 m. L2 is sited at mid-lake with a depth of 40 m. L3 is situated close to the dam wall with a depth of 45 m as shown in Figure 6.20. The residence time of the water in the reservoir is approximately 130 days (Taranaki Catchment Board, 1988). The data from the three stations were not combined and were analysed as if each station were part of a different lake. The data were variable, as the lake was affected by flood events and seasonal patterns were not distinct. Only one significant PAC value was calculated from the 12 sets of data (four key variables for three stations); that was a -4.3% $year^{-1}$ decrease in TN at L3 (Figure 6.21). The average PAC value for L1 and L2 was 0.0 and for L3 it was -1.08% $year^{-1}$ with a *p*-value of 0.39. Thus the PAC values indicated that there was no change in the trophic level of Lake Rotorangi during the period of its monitoring.

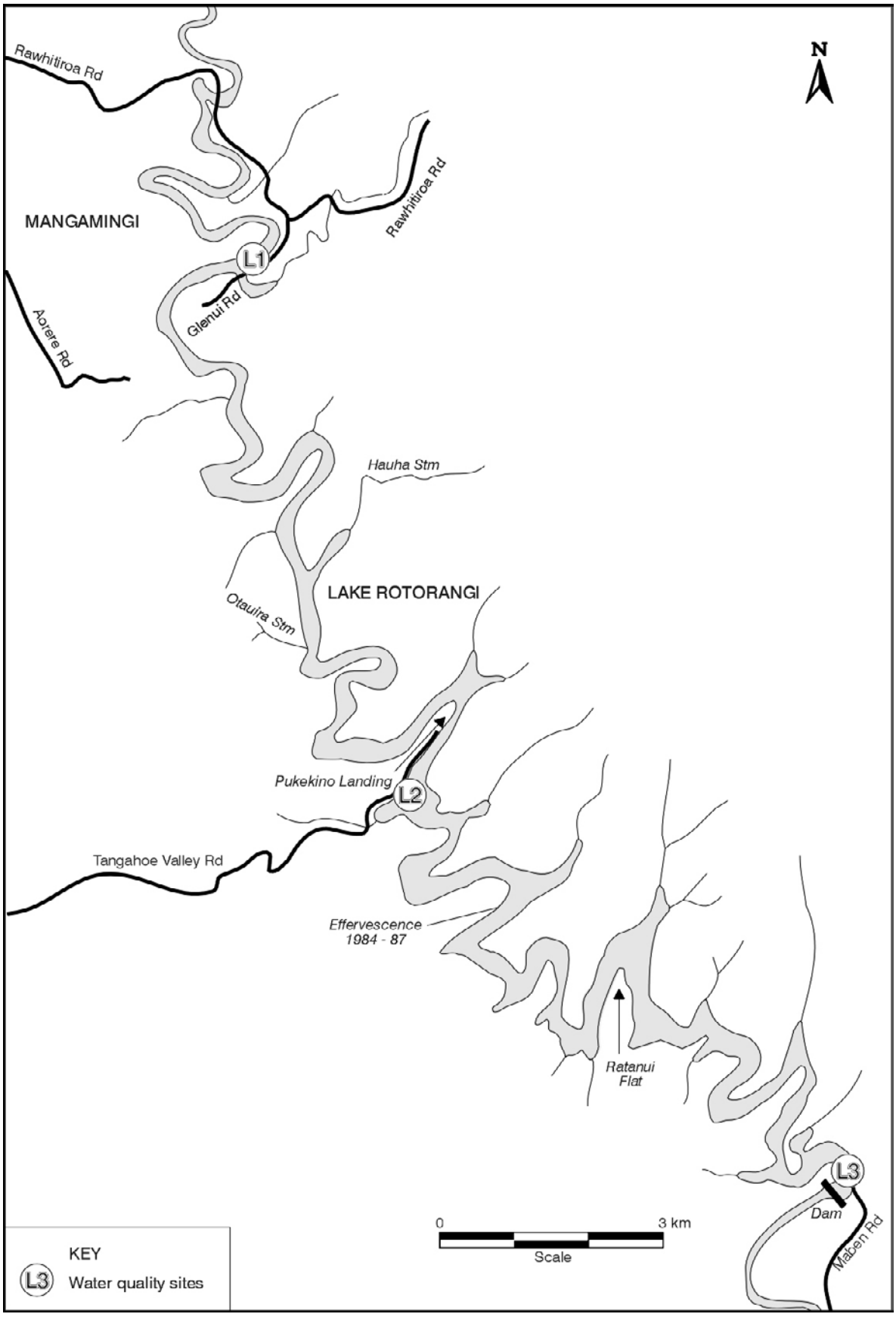


Figure 6.20: Map showing Lake Rotorangi and its sampling stations

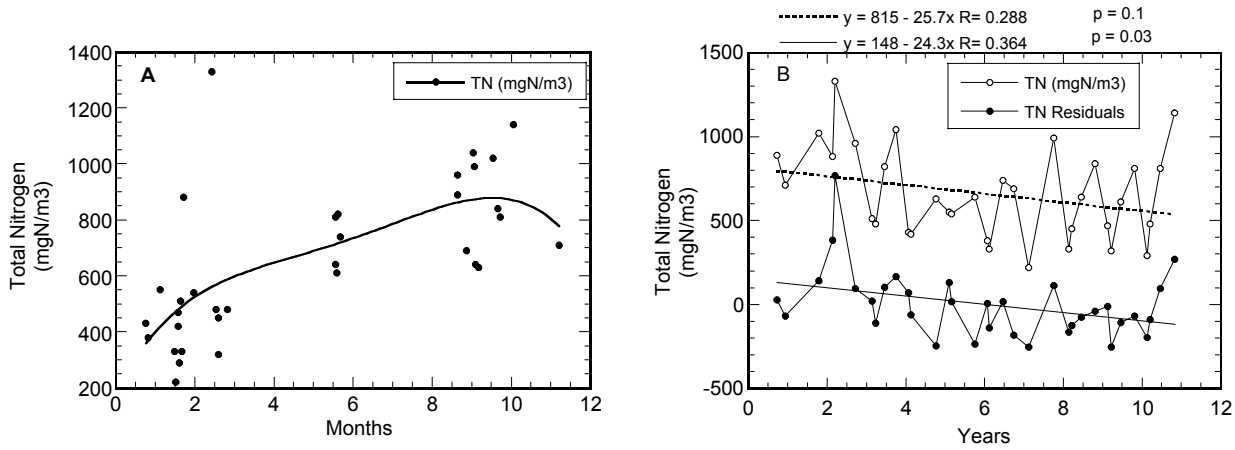


Figure 6.21: Plots of annualised data (A) and time trends of observed and residual values (B) for Station L3, Lake Rotorangi

The TLI values calculated for the three stations for the years when all four TLx values were available are shown in Table 6.9. The TLx values for L1 for SD, TP and TN are similar with an average of 4.97 TLI units, which is much higher than the TLc value of 2.93 (Table 6.9). At L2, the TLp and TLs values are similar but lower than TLn. The TLc is again low, although it is slightly higher than at L1. At L3 TLn is similar to its level at L1 and L2, but TLs and TLp are lower than at L2 and L1. The TLc is at its highest at L3 at 3.35 TLI units and is approaching the values of TLs (3.82) and TLp (3.63) at L3.

Table 6.9: Trophic Level Index values calculated for Lake Rotorangi

Station / period	Chla	SD	TP	TN	TLc	TLs	TLp	TLn	TLI	Std
	(mg m^{-3})	(m)	(mg m^{-3})	(mg m^{-3})		(TLI units)				dev
L1										
95–96 averages	1.8	0.6	65.0	715	2.85	5.54	5.49	4.98		
96–97 averages	1.8	2.0	42.3	665	2.84	4.37	4.95	4.89		
97–98 averages	2.2	1.4	35.0	743	3.09	4.72	4.71	5.03		
Average TLx					2.93	4.88	5.05	4.97	4.46	0.30
L2										
95–96 averages		2.51				4.13				
96–97 averages	2.28	2.36	20.8	508.5	3.13	4.19	4.05	4.54		
97–98 averages	2.15	2.36	23.3	690	3.06	4.19	4.19	4.93		
Average TLx					3.10	4.17	4.12	4.74	4.03	0.20
L3										
95–96 averages	2.58	3.16	17.8	595	3.26	3.88	3.85	4.74		
96–97 averages	2.85	3.7	12	555	3.38	3.71	3.36	4.65		
97–98 averages	2.93	3.26	15.5	591	3.40	3.85	3.68	4.73		
Average TLx					3.35	3.82	3.63	4.71	3.88	0.17

The interpretation of the TLI results is that the water at L1 is essentially riverine in character with a low Chla value and relatively high SD and TP values because of the suspended sediment content of the water. On the other hand, the water at L3 is lacustrine in character with the TLc, TLs and TLp almost in balance with each other, indicating that the phytoplankton growth has probably reached the full growth potential possible with the available phosphorus. The lower TLs at L3, which is almost in balance with the TLc and TLp, indicates that most of the river-borne sediment has settled out. The TLn values are interesting in that they show only a small decrease between L1 and L3. Also, at L2 and L3, the TLn values are much higher than those of TLp. This suggests that TN availability is surplus to phytoplankton requirements and that phosphorus is the growth-limiting nutrient. Phosphorus is diminished more by phytoplankton growth and sedimentation than is nitrogen. Nitrate levels in the reservoir remain high.

The equations based on New Zealand lake data to determine TLI values did not apply to the reservoir data when it was still riverine in nature at Station L1 in Lake Rotorangi. However, when this water had travelled slowly down the lake for more than 100 days at an approximate speed of 300 m day^{-1}, the TLI values calculated for this water could be interpreted as those of a mesotrophic lake with the Chla, SD and TP levels in balance with each other, and having surplus available nitrogen. The TLI system for lake classification can apparently be used on reservoir data to describe the nature of the reservoir water if it has resided in the reservoir for more than 130 days . The method of deseasonalising data and detecting trends with time described in this study worked satisfactorily with reservoir data.

6.4 State of the environment reporting

The previous examples demonstrate the large degrees of difference that can exist between lakes. However, if each regional council reported the results of its monitoring in a similar manner, it would enable the Ministry for the Environment to summarise the information received and issue reports periodically on the state of the nation's lakes. Regional councils should report for each monitored lake:

- its condition – stable, improving or deteriorating – by using the PAC results for the lake
- its recent annual averages and TLI values
- the TLI value and TLI trend.

An example of such a report for Lake Okareka, generated by the program LakeWatch, is shown in Figure 6.22.

Okareka

Okareka Analysis (1 Sep 1992Ğ31 Aug 1995)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	0.32	-0.85	1.25	(-2.61)	(-4.50)			
Average Over Period	2.21	9.18	7.66	(174.91)	(56.24)			
Percent Annual Change (%/Year)	**14.48**	**9.26**	**16.32**	**0.00**	**0.00**	**8.01**	**3.47**	**0.08**

Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Sep 1992 - Aug 1993	2.03	10.02	7.32	178.20	3.00	2.54	2.74	3.17	2.86	0.14			
Sep 1993 - Aug 1994	2.04	9.48	6.91	171.45	3.01	2.62	2.67	3.11	2.85	0.12			
Sep 1994 - Aug 1995	2.61	7.96	8.66	179.20	3.28	2.84	2.96	3.17	3.06	0.10			
Averages	**2.23**	**9.15**	**7.63**	**176.28**	**3.10**	**2.67**	**2.79**	**3.15**	**2.93**	**0.07**	**0.10**	**0.08**	**0.2672**

SUMMARY:

PAC = 8.01 ± 3.47 % per year
P-value = 0.08

TLI value = 2.93 ± 0.07 TLI units
TLI trend = 0.10 ± 0.08 TLI units per year
P-value = 0.2672

ASSESSMENT:
Oligotrophic
Definite Degradation

The guide used in the PAC average *P*-Value evaluation is

P-Value Range	Interpretation
< 0.1	Definite Change
0.1 - 0.2	Probable Change
0.2 - 0.3	Possible Change
>0.3	No Change

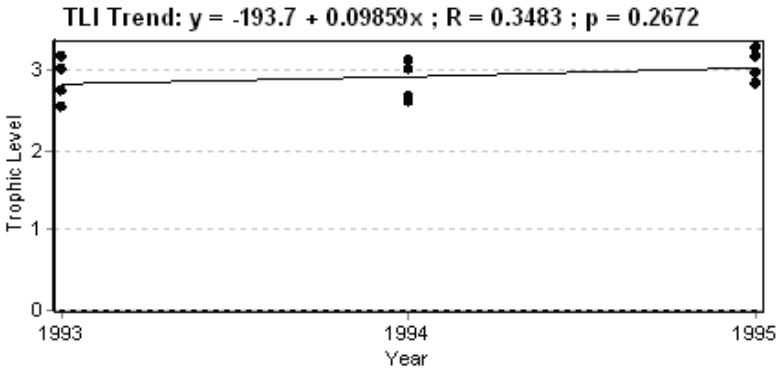


Figure 6.22: An example of a lake report summarising essential information for environmental reporting

Chapter 7. Optimised sampling strategies

7.1 Optimised lake sampling

Regional councils need to use the money allocated to lake monitoring with maximum efficiency: the money budgeted to this task is seldom adequate to meet the requirements of monitoring for sustainable management. Most administrators are very busy with day-to-day problems and do not easily think in terms of a 20-year (or even a 50-year) perspective. However, a long-term outlook is needed. Environmental degradation is insidious, with virtually undetectable deterioration in water quality happening on a year-to-year basis. Over the years those small changes eventually add up to a large degradation in the state of lakes in a region.

To control this slow loss of environmental quality in lakes their current state should be measured with baseline monitoring: this creates definitive benchmarks that can be compared with future measurements of trophic level. Creation of an absolute measure of the water quality of each lake in a region for future reference is the only way of determining if lakes are degrading slowly and require protection against the pressures of future increased population and land use in their catchments.

Baseline monitoring

Baseline monitoring of a lake is undertaken to:

- set up a secure TLI value as a benchmark for comparison against future values
- provide information on the basic limnology of a lake
- enable establishment of an efficient and economic system of routine monitoring for a lake.

A lake undergoing baseline monitoring should have a minimum of two sampling stations on it. One station should be located over the deepest part of the lake, the other as far as possible from the first station but still over a deep part of the lake. Sampling at a station should be monthly and according to the procedures detailed in chapter 2. The samples should be analysed for Chla (epilimnion only), TP, TN, DRP, NO_3 + NO_2, NH_4 and pH; some sample water should be set aside and preserved with Lugol's solution for phytoplankton identification. Baseline sampling should be carried out for a minimum of two years, but preferably for three years. A shallow lake undergoing baseline sampling should be surveyed once during baseline monitoring to determine the nature and extent of its macrophyte flora.

Baseline monitoring programmes are set up to include a measure of deliberate over-sampling. Analysis of the data can then eliminate subsequent unnecessary data collection while ensuring that an effective routine sampling programme, with all necessary data collection, is put in place. This is illustrated by the monitoring programme for Lake Hayes and is discussed in section 5.1. The data are first checked to see whether there is any spatial correlation in the data: ie, are both stations giving essentially the same information? If they are, then only one sampling station is needed. The data for one station on a particular day are plotted against the equivalent data from the other station (*see* Figure 5.2). The conclusion from these results is that only one sampling station is needed on Lake Hayes because the five key variables are strongly spatially correlated.

Routine monitoring

Routine monitoring programmes can be set up after baseline monitoring has been completed. Although the baseline monitoring has determined the essential data for collection, the routine monitoring programmes should be ready to adapt to changing circumstances. For example, if a town grows so that new storm drains are installed along a section of shoreline, it may be necessary to create

a new sampling station just offshore from the drains to check on their impact. The drains should also possibly be monitored for a period.

The next issue to check is whether there is temporal correlation in the data: are the values of samples taken during one month related to those taken the month before? This is illustrated in the analysis of Lake Hayes data (*see* section 5.1; Figure 5.3).

In the matter of sampling frequency, the general guideline is 'the more frequent the sampling, the better is the capability of observing year-to-year change'. Moreover, if variables show a pattern of annual maximum or minimum values, they need to be observed each year. Examples of annual maxima are shown in Figures 5.5 (E, F), and 6.8 (A, B). If such sites are sampled one year and missed the next, noticeable differences can occur between the averages from one year and another sampling year: the significance levels of time trend lines can be affected.

For stratified lakes, sampling frequency may be governed also by the need to measure hypolimnetic oxygen concentrations. For Lake Okareka (*see* section 6.2), for example, monthly sampling permits only five observations of hypolimnetic DO concentration from October to February before the variable drops below 2 g m^{-3} (concentrations below this level cannot be used in determining HVOD rates): this is close to the minimum number of observations for determination of reliable HVOD rates. Then, from March to July, the lake needs to be monitored for possible anoxic regeneration of nutrients. The isothermal waters of Lake Okareka also need observation for possible maxima of Chla and TP values in August of each year. Thus, September is the only month when it is not critical to sample Lake Okareka. Given that Lake Okareka may be becoming more eutrophic and needs careful watching, monthly sampling is optimal for this lake. Similarly, consideration of Lake Hayes data (*see* section 5.2; Figure 5.5) leads to the conclusion that, if necessary, sampling of this lake could be omitted during the months of February, April and August.

Optimum sampling for routine monitoring would be monthly if possible, but with the omission of some months if necessary. Should the number of samplings need to be diminished drastically, it would be better to have non-sampling years. Once the baseline monitoring of a lake has been done, the lake need not be monitored intensively each year. Monitoring frequency can be diminished either by reducing the number of samplings each year or by having years when no sampling is done – sometimes this presents a difficult choice. However, valid TLI values can be calculated only from good annual average values. This would require at least eight samplings per year which, in turn, favours a pattern of sampling years interspersed with non-sampling years.

In deciding on routine monitoring sampling frequency, the need for monitoring a lake should be established on the basis of its importance to its region and the probability of its deterioration. Lakes in a region could be divided into three classes of priority for monitoring. The nature of the lakes should also be considered. If a lake is very seasonal in its nature, it is better sampled monthly; but if it is not, as is true of many shallow lakes, it can be sampled at a reduced frequency. Thus:

- a Class 1 lake would be sampled monthly each year
- a Class 2 lake would be sampled monthly every second year or six times per year each year, if shallow
- a Class 3 lake would be sampled monthly every third year or four times per year each year if shallow.

Lakes undergoing routine sampling would possibly have only one sampling station, as discussed above. The samples collected would be analysed for the same suite of variables as for a sample from baseline monitoring, but with only one aggregated phytoplankton sample per year. However, if necessary, routine analyses could be reduced to the minimal analyses of Chla, TP and TN samples, besides measurement of SD and DO/temperature profiles. This matter of reducing analytical costs should be considered carefully because the loss of information is significant while the money saved in analytical costs can be quite small when compared with the irreducible costs of the collection of the samples, personnel time, and vehicle and boat usage.

7.2 Critical factors in developing a monitoring strategy

Various factors and costs have to be determined before developing a monitoring strategy:

- the monitoring priority for each lake, based on the importance of the lake to the community, susceptibility of the lake to deterioration and the need to obtain baseline data on the lake
- the cost of sampling of a station on each different lake, based on the time spent on the lake to carry out the required procedures and the analytical cost of the variables chosen for analysis
- the cost of the sampling team's travel to the lake
- the cost of data surveillance to ensure that good-quality data are obtained, analysed and reported
- the depreciation cost of equipment, including good field equipment (such as an appropriate boat, field instruments and vehicle)
- the approximate size of a lake monitoring budget.

These are the basic building blocks in developing a regional lake monitoring strategy.

An example of a straightforward, hypothetical regional council lake monitoring strategy is presented in the next section as the best way to explain how a monitoring strategy can be developed. Although different regional councils have different problems, the example demonstrates the main principles that need to be considered.

7.3 A hypothetical lake monitoring strategy

This example of a regional lake monitoring strategy is based on some of the lakes in the Rotorua district but is completely hypothetical and does not relate in any way to the monitoring strategies currently in place in this region. The help of Environment Bay of Plenty in determining realistic costs and time expenditures for use in this example is gratefully acknowledged. (All costings presented in the example are in New Zealand dollars.)

The Lakeland Regional Council has offices and laboratories in Whakatane and is responsible for the six lakes shown in Figure 7.1. The current state of information on these lakes is as follows:

Rotorua:	two years of baseline monitoring information; spatially correlated – one station needed
Rotoiti NI:	two years of baseline monitoring information; not spatially correlated – two stations needed
Okareka:	two years of baseline monitoring information; spatially correlated – one station needed
Rotoma:	no reliable monitoring information to date
Okaro:	no reliable monitoring information to date
Rotoehu:	no reliable monitoring information to date.

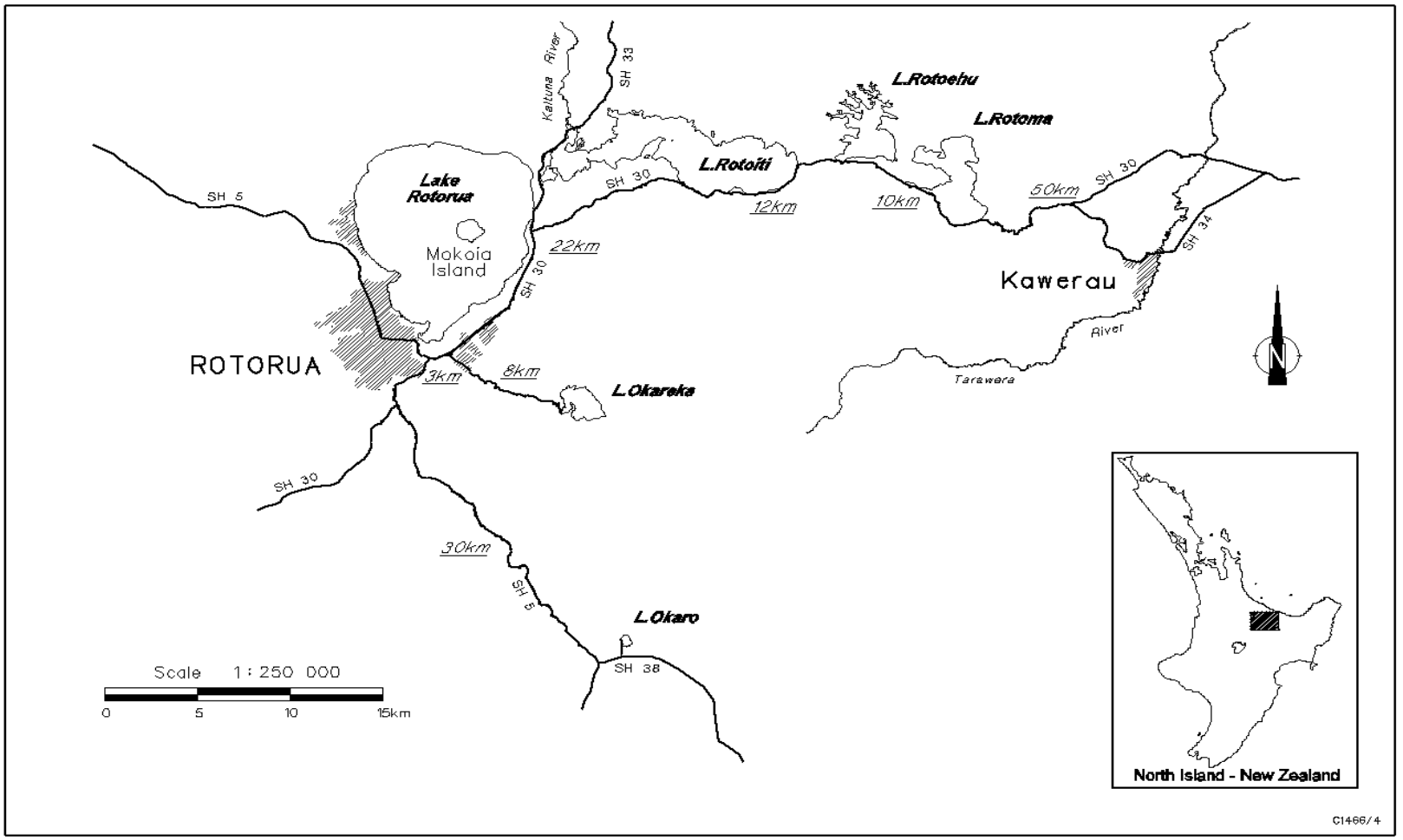


Figure 7.1: A map of the Lakeland District, showing the location of the lakes to be monitored and some highway distances

Establishing critical factors

The information collected in regard to the six factors listed in section 7.2 is as follows:

Monitoring priority

The lakes are classified in importance as follows:

Class 1

Lake Rotorua. This lake is the most important in the region for economic and public relations reasons. Further, an expensive scheme of sewage diversion from the lake was undertaken in 1991 and it is important to monitor the response of the lake to this decrease in inputs.

Class 1 lakes will undergo baseline sampling every year.

Class 2

Lake Rotoiti. This lake is heavily used by residents of the area and tourists. Also, its inflow consists largely of water from Lake Rotorua, so the hope that improvement in the water quality of Lake Rotorua will lead to improvement of Lake Rotoiti waters needs to be checked.

Lake Okareka. This lake has a significant number of permanent residents living around it. It is a pretty lake used by tourists but is in danger of experiencing a decrease in water quality as a result of inputs from the high-use septic tanks and the pasture surrounding the lake.

Class 2 lakes will undergo minimum or routine sampling every year.

Class 3

Lake Rotoma. This is a very clean and lovely lake. Its water quality appears not to be under threat at present.

Lake Okaro. This is a small lake that became very eutrophic years ago when the land around it was converted to pasture. It is extensively used for water skiing.

Lake Rotoehu. This is a shallow lake that receives geothermal inputs and has suffered from blue-green algal blooms in recent years. It is not as heavily used as the other lakes in the region.

After baseline monitoring, class 3 lakes will be monitored for one year in three. If any of these lakes gives an indication of change, the monitoring strategy will have to be altered to improve their frequency of sampling.

Cost of sampling

Calculation of costs of sampling times and travelling times for each of the six lakes was considered to be costing in unnecessarily fine detail for the Lakeland situation. Lake Okaro is some distance from the other lakes: when it is sampled, the number of lakes that can be sampled on that day is reduced by one. For a baseline monitoring visit to a lake, the cost of analysing samples for two stations is $300 for both stations for analytical chemistry and $60 for a single phytoplankton sample aggregated from both sampling stations. Routine monitoring of Lakes Okareka and Rotoiti – sampled at one station only and with only one aggregated phytoplankton sample per year – would cost $160 for analysis of one sampling. A single minimum monitoring sampling would cost $60 for chemical analysis. Costs of macrophyte surveys are also estimated. Thus:

Analytical cost of a baseline sampling of a lake	= $360
Analytical cost of a routine sampling of a lake	= $160
Analytical cost of minimum sampling of a lake	= $60
Complete cost of a macrophyte survey of Lake Rotorua	= $4,000
Complete cost of a macrophyte survey of Lake Rotoehu	= $3,000

Cost of travel

A map of the Lakeland Region with the location of the lakes and travelling distances marked on it is shown in Figure 7.1. The cost of having the field sampling team in the field for a day is as follows:

Two persons @ $400 each per day	= $800
Vehicle per day (average of 200 km per round trip)	= $100
Use of boat per day	= $160
Total field cost per day	= $1,060

Cost of data surveillance

Staff time for data entry, data surveillance and annual data analysis	= $4,000 pa

Depreciation cost of equipment

Cost of computer usage	= $1,700 pa
Depreciation of sampling equipment	= $1,400 pa
Total fixed costs ($4,000 + $1,700 + $1,400)	= $6,900 pa

Lake monitoring budget

Size of lake monitoring budget	= $30,000 pa

A special budget allocation will be made every fifth year to cover the cost of an in-depth status report:

Report estimated at approximately one month staff time	= $16,000 per report

Expenditure options

Calculation 1

Cost of two field days per month (24 per year x $1,060)	= $25,440 pa
Fixed costs	= $6,900 pa
Total cost per year	*$32,340*

The field costs alone, without analytical costs, exceed the annual budget. Therefore two field days per month are not possible.

Calculation 2

Option 1a: two baseline + two minimum samplings per month

Cost of one field day per month	= $12,720 pa
Fixed costs	= $6,900 pa
Analytical cost of baseline sampling of two lakes (24 @ $360)	= $8,640 pa
Analytical cost of minimum sampling of two lakes (24 @ $60)	= $1,440 pa
Total cost per year	*$29,700*

Option 1a is feasible: it comes in just within budget.

Option 1b: the same as option 1a, but replacing the minimum sampling of two lakes with routine sampling as described in section 7.1.

Analytical cost of routine sampling of two lakes (24 @ $160)	= $3,840 pa
Total cost per year ($29,700 - $1,440 + $3,840)	*$32,100*

Option 1b is possible if a budget increase of $2,000 is requested and granted.

Option 2: one baseline + four minimum samplings per month.

Analytical cost of baseline sampling of one lake (12 @ $360)	= $4,320 pa
Analytical cost of minimum sampling of four lakes (48 @ $60)	= $2,880 pa
Fixed costs	= $6,900 pa
Field costs	= $12,720 pa
Total cost per year	*$26,820*
Balance unused per year ($30,000 - $26,820)	*$3,180*

The balance of $3,180 could be used to pay for a macrophyte survey of Lake Rotoehu at $3,000 or Lake Rotorua at $4,000 (if an extra $820 is requested).

Option 3: one baseline + three routine samplings per month.

Analytical cost of baseline sampling of one lake (12 @ $360)	= $4,320 pa
Analytical cost of routine sampling of three lakes (36 @ $160)	= $5,760 pa
Fixed costs	= $6,900 pa
Field costs	= $12,720 pa
Total cost per year	*$29,700*

Strategy considerations for optimal monitoring

Although option 2 above enables the sampling of five lakes plus a macrophyte sampling, option 1 is preferred because it permits both Lake Rotorua and another lake to undergo baseline sampling each year. The Lakeland Regional Council considers Lake Rotorua to be important and sufficiently in the political spotlight to require information on the lake that is unequivocal and beyond question. It should thus undergo a programme of full-time baseline sampling.

Another serious consideration is that the three lakes that have not undergone baseline sampling should have their benchmark state established as soon as possible. Thus, the first six years of the strategic plan will incorporate two years of baseline sampling on each of Lakes Okaro, Rotoehu and Rotoma. Sampling of Lake Rotorua can be downgraded for one of the six years from baseline sampling to routine or minimum sampling to allow for a macrophyte survey of Lake Rotoehu.

The 10-year sampling plan

Years 1 and 2	Option 1a	Lakes Rotorua and Okaro – baseline sampling
		Lakes Okareka and Rotoiti – minimum sampling
		Cost $29,700 per year.
Years 3 and 4	Option 1a	Lakes Rotorua and Rotoma – baseline sampling
		Lakes Okareka and Rotoiti – minimum sampling
		Cost $29,700 per year.
Year 5	Option 2	Lake Rotoehu – baseline sampling and a macrophyte survey
		Lakes Rotorua, Okareka, Rotoiti – minimum sampling
		Cost $29,820 per year.
Year 6	Option 1a	Lakes Rotorua and Rotoehu – baseline sampling
		Lakes Okareka and Rotoiti – minimum sampling
		Cost $29,700 per year.
Report on first five years sampling		Cost $16,000.

Year 7	Option 2	Lake Rotorua – baseline sampling and a macrophyte survey Lakes Okareka, Rotoiti and Okaro – minimum sampling Cost $30,820 per year.
Year 8	Option 3	Lake Rotorua – baseline sampling Lakes Okareka, Rotoiti and Rotoma – routine sampling Cost $29,700 per year.
Year 9	Option 3	Lakes Rotorua and Rotoiti – baseline sampling Lakes Okareka, Rotoiti and Rotoehu – routine sampling Cost $29,700 per year.
Year 10	Option 3	Lake Rotorua – baseline sampling Lakes Okareka, Rotoiti, and Okaro – routine sampling Cost $29,700.

There is little value to continue planning after this point because situations change with time. The first and most important task of year 11 would be the production of the report on the 10 years of monitoring. This should conclude with a strategic plan for the next 10 years of monitoring. (It is hoped that the lake monitoring budget was increased by $2,000 each year on presentation of the draft monitoring plan so that routine sampling was possible when required instead of minimum sampling.)

The important issue for the future is that all strategic monitoring plans should ensure the ability to determine whether any of the lakes are changing by comparing current TLI values against the original values. If any lake is found to be changing in trophic state, it may be necessary to set up a diagnostic investigation to find the cause of change if this is not obvious.

References

APHA, 1998. *Standard Methods for the Examination of Water and Wastewater*, 20th edition. American Public Health Association: 1015 15th Street NW, Washington, DC 20005-2605.

Bell, RG, Goring, DG 1998. Seasonal variability of sea level and sea-surface temperature on the north-east coast of New Zealand. *Estuarine and Coastal Shelf Science* 46: 307–318.

Blomkvist, D, Lundstedt, L 1995. Sediment investigation of the Rotorua Lakes. Environment B.O.P report 95/23: Whakatane, New Zealand.

Burns, NM 1995. Using hypolimnetic dissolved oxygen depletion rates for monitoring lakes. *New Zealand Journal of Marine and Freshwater Research* 29: 1–11.

Burns, NM 1999. *A monitoring strategy for the Rotorua district lakes.* Lakes Consulting report 99/1: Pauanui, New Zealand.

Burns, NM, Deely, J, Hall, J, Safi, K 1997. A comparison of past and present trophic states of seven central volcanic plateau lakes. *New Zealand Journal of Marine and Freshwater Research* 31: 71–87.

Burns, NM, Rutherford, JC 1998. *Results of Monitoring New Zealand lakes, 1992–1996.* NIWA Hamilton client report MFE80216: Hamilton, New Zealand.

Burns, NM, Rutherford, JC, Clayton JS 1999. A monitoring and classification system for New Zealand lakes and reservoirs. *Lakes and Reservoir Management* 15: 255–271.

Carlson, RE 1977. A trophic state index for lakes. *Limnology and Oceanography* 22: 361–369.

Cassie, V 1984. *A revised checklist of the freshwater algae in New Zealand (excluding diatoms and charophytes).* Parts 1 and 2, Water and Soil miscellaneous publication 26. Ministry of Works and Development: Wellington. 116 p and 250 p.

Champion, P 1995. Egeria densa *in Lake Omapere*. Communication to Northland Regional Council. NIWA: Hamilton.

Chapra, SC, Dobson, FH 1981. Quantification of the lake trophic typologies of Nauman (surface quality) and Thieneman (oxygen) with special reference to the Great Lakes. *Journal of Great Lakes Research* 7: 182–193.

Clayton, JS, Wells, RDS 1989. *Aquatic weed control in the Rotorua Lakes, a technical evaluation.* Ministry of Agriculture and Fisheries: Hamilton, New Zealand.

Data Description Inc (undated). *Data Desk*. Data Description Inc: PO Box 4555, Ithaca NY 14852, United States.

Davies-Colley, RJ, Vant, WN, Smith, DG 1993. *Colour and Clarity of Natural Waters.* Ellis Horwood, Chichester: 300 p.

Deely, JM 1998. *Summary of water quality of Lakes Okareka and Tarawera and the channel connecting these two lakes.* Environment B.O.P environmental report 98/24: Whakatane, New Zealand.

Deely, JM, McIntosh, JJ 1998. *Bathing suitability survey 1998*. Environment B.O.P. environmental report 95/92.

Department of Lands and Survey 1986. *Lake Okareka Scenic Reserve Management Plan*. Department of Lands and Survey: Hamilton, New Zealand.

Donald, R 1997. *Rotorua Lakes Summary Report.* Environment Bay of Plenty report 97/21: Whakatane, New Zealand.

Donovan, WF, Don, GL 1991. *Lake Okareka nutrient input report*. Bioresearches: Auckland. 56 p.

Etheridge, MK 1985. Phytoplankton methodology: some recommendations for routine analysis. *In*: *Biological monitoring in freshwaters.* Water and Soil miscellaneous publication 82. Ministry of Works and Development: Wellington. 55–70.

Froude, VA, Richmond, CJ 1990. *Aquatic weed control in the Rotorua lakes*. Department of Conservation Report: Rotorua, New Zealand.

Gall, MP, Downes, MT 1997. *Algal pigment stratigraphy in four Rotorua lakes: Okataina, Okareka, Okaro and Rotorua.* NIWA client report no. CH97-78 to EBOP: Christchurch, New Zealand.

Grashoff, K, Ehrhardt, K, Kremling, K (ed.) 1983. *Methods of seawater analysis*. Verlag Chemie: Basel. 393 p.

Jolly, VH 1959. *A limnological study of some New Zealand lakes*. Unpublished PhD thesis, University of Otago: Dunedin.

Knowlysis 1998. *LakeWatch*. Knowlysis Ltd: PO Box 90-058, Auckland, New Zealand. Email: lakewatch@knowlysis.co.nz

Lind, OT 1974. *Handbook of Common Method in Limnology*. Mosby: Saint Louis. 154 p.

Microsoft Corporation (undated). *Excel*. Microsoft Corporation: 1 Microsoft Way, Redmond, WA98052-6399, United States.

Prescott, GW 1962. *Algae of the western Great Lakes area*. Brown: Dubuque, Iowa; reprinted 1982; Otto Koeltz Science: Koenigtein, Germany. 977 p.

Pridmore, RD, Etheridge, MK 1987. Planktonic cyanobacteria in New Zealand inland waters; distribution and population dynamics. *New Zealand journal of marine and freshwater research* 21: 491–502.

Pridmore, RD, Hewitt, JE 1982. *A guide to common freshwater algae in New Zealand*. Water and Soil miscellaneous publication 39. Ministry of Works and Development: Wellington. 45 p.

Scanlan, M 1994. *Safety in small craft*. New Zealand Coastguard Federation: PO Box 345, Auckland.

Synergy Software (undated). *Kaleidagraph*. Synergy Software: 2457 Perkiomen Av., Reading, PA 19606, United States.

Taranaki Catchment Board 1989. *Lake Rotorangi – monitoring a hydro lake*. Taranaki Catchment Board: Stratford, New Zealand.

Vallentyne, JR 1974. *The algal bowl*. Department of the Environment: Ottawa, Canada. 154 p.

Vant, WN (ed.) 1987. *Lake manager's handbook*. Water and Soil miscellaneous publication no. 103. National Water and Soil Conservation Authority: Wellington, New Zealand. 222 p.

Wallace, P 1999. *Lake Okareka level control*. Environment Bay of Plenty operations report 98/18: Whakatane, New Zealand.

Ward, J, Pyle, E 1997. *Environmental indicators for the sustainable management of fresh water*. Lincoln Environmental report no. 2416/1.

White, E 1977. *A multiple use classification for New Zealand's lakes*. Report to the Officials Committee on Eutrophication.

White, E, Law, K, Payne, G, Pickmere, S 1985. Nutrient demand and availability among planktonic communities – an attempt to assess nutrient limitation to growth in 12 central volcanic plateau lakes. *New Zealand Journal of Marine and Freshwater Research* 19: 49–62.

YSI, 1981. *Instruction Manual for YSI Model 58 Dissolved Oxygen Meter*. Yellow Springs Instrument Co Ltd: Yellow Springs, Ohio 45387, United States.

Appendices: Check and action lists

Appendix 1: Sampling equipment and procedures

Boat check list

- trailer: includes warrant of fitness, tyres, tow coupling, lights and safety chain; also check braking system if present (this will include brake fluid)
- items on boat: battery, electrics, petrol, oil and water, all safety equipment including life-jackets, anchor, chain and anchor warp (and check that anchor is attached to warp), radio check, depth sounder
- auxiliary outboard, if fitted (includes petrol, spare plugs and servicing)
- tool box.

Calibration checks prior to field trip

- Thermometer checks. Check at two temperatures to confirm meter is holding its calibration. Do this at the lower and higher temperature ranges likely to be encountered in the field. Use last sampling run as a guide.
- Dissolved oxygen probe. After temperature checks, check that the DO probe is working. Also check for bubbles, wrinkles or any damage to the membrane.
- *Note*. Have a copy of a profile sheet from previous sampling available for reference on the boat.

Equipment check list

- dissolved oxygen meter – includes cable attached to meter, weight attached to cable and probe; probe must be wrapped with a sponge and in a plastic bag; turn meter on at beginning of day
- mixing containers for equilibrating lake water with air
- thermos flask for DO meter calibration
- Van Dorn sampler and Van Dorn messenger unit
- Secchi disc attached to either marked rope or tape
- Secchi disc viewer
- chilly bins packed with ice
- sample bottles
- large mixing container for mixing epilimnion samples
- funnel
- temporary bouys if needed
- depth sounder
- field sheets, instructions and marker pen for labelling
- spares – spare DO glands, KCl solution, scissors, Allen keys, pencils and Van Dorn rubber
- GPS if needed.

Field preparation

- Load all equipment into boat according to “Equipment check list” above.
- Check boat according to “Boat check list” above.
- Do calibration checks according to “Calibration checks prior to field trip”.
- Check that boat is adequately attached to trailer and that all tie-downs and chains etc are tight.

Taking a sample

The following list of events presumes that the boat is anchored at the sampling station.

- Fill out the top of the field data sheet. Lake name, site code, area, names of sampling staff, day, date, time and cloud cover. Lake height can be taken before going onto the lake or after sampling has finished. (Staff gauges and water level recorders are rarely beside boat ramps.)
- Mix the air saturated sample. Pour lake water from container to container a minimum of 20 times and place in thermos flask with DO probe.
- Measure the Secchi disc depth – two observations as per procedure. Write results on field data sheet.
- Record the temperature of the air saturated water and set the meter to 100%.
- Measure the DO/temperature profile at the appropriate depths recording all the values on the temperature profiling sheet and graphing the dissolved oxygen and temperature on graph paper. Refer to profile sheet from previous sampling.
- Fill in the maximum depth on the field sheet.
- Determine whether the lake is isothermal or stratified and take Van Dorn bottle samples as per sampling depths on the field data sheet. Transfer the water to the appropriate sample bottle: 1-litre container for the chemical analysis and the 5-litre container for the chlorophyll *a* and phytoplankton samples.
- Put all samples on ice.
- Check field sheet has all relevant data filled in.
- Stow all gear and move to next sampling station.

Return to base

- Dispatch samples to laboratory or hand samples into the laboratory as soon as possible after return to base.
- Filter the chlorophyll *a* sample and procure the phytoplankton sample immediately on return to base according to procedure “Filtering of the chlorophyll *a* sample” (*see* section 2.7).
- Unload all sampling gear. Special attention must be given to the following:
- Dissolved oxygen meter. Store dry
- Probe. Inspect gland for damage and wrap in a moist sponge and place in a sealed plastic bag.
- Van Dorn sampler. Inspect rope for damage where the messenger hits the firing mechanism on the Van Dorn. Place paper towels in the rubber jaws to prevent the rubber jaws sticking.
- Secchi disc. Dry out before storing and touch up paint if disc has become chipped.
- Boat. Ensure any maintenance is carried out before next sampling run.
- Make sure all equipment is dry before storage and repair any faults noticed during the sampling run.

Appendix 2: Action list for laboratory processing of samples

This list gives a brief outline of the steps to be taken to suitably handle and process samples upon receipt in the laboratory. It is assumed that the laboratory, in time, will produce more detailed guidelines in accordance with its own established practices.

Samples should preferably be processed upon the day or receipt. If this is not possible, then samples should be stored in the fridge overnight (not a freezer, because this will alter pH and possibly dissolved nutrient concentrations). Note on the laboratory worksheet if samples have been held over.

Initial sample processing

- Formally enter the samples into the laboratory register. Each sample (comprising a 1-litre and 2-litre bottle) should have its own unique laboratory identification number.
- Head up an appropriate laboratory worksheet to record relevant sample details (cross-referenced with the unique laboratory identification number) and results of any measurements made.
- Label sample sub-containers for sample splitting: (i) TP/TN analyses (ii) dissolved nutrient analyses turbidity and (iii) conductivity measurements (if applicable).
- Carry out calibration checks on pH meter and electrode. Also conductivity and turbidity meters if applicable.
- Warm up chilled 1-litre samples to 20–25°C (in sink of hot water).
- Shake 1-litre sample container well to create homogeneous solution.
- Measure pH directly in 1-litre bottle (take care to avoid introducing any contamination, eg, always rinse electrode in deionised water before measuring pH).
- Re-cap 1-litre sample bottle, re-shake.
- Dispense appropriate volume of shaken sample into a sub-container for TP/TN analyses.
- Dispense appropriate volume of shaken sample into a sub-container for turbidity and conductivity measurements.
- Filter (using 0.45-micron membrane filter) appropriate volume of sample (settled, if necessary, to leave behind heavy sediments) into a sub-container for dissolved nutrient analyses. Rinse filtration system first with several aliquots of deionised water, then an aliquot of sample, before collecting the sample proper).
- Store sub-containers in a freezer until time of analysis.
- Measure conductivity and turbidity (if applicable) using sample in/from the sub-containers. Note: this could be done on remaining sample in the 1-litre bottles provided this is the last activity carried out on the sample.
- Chlorophyll *a* filtration. From 2-litre sample bottle, filter an established volume of sample (up to 1 litre) through an appropriate size GF/C filter. Fold and place filter in a labelled plastic or tinfoil wrap and store frozen until time of analysis. Note: this activity should be completed as soon as possible.
- Suspended solids filtration. Also from 2-litre sample bottle, filter an established volume of sample through an appropriate size GF/C filter that has been pre-dried and pre-weighed. Place the filter (with retained residue) into a labelled holding dish or tray, and put into the drying oven. Filtration is non-urgent and may be delayed several days if necessary.
- Once samples have been processed, sample bottles may be recycled: use the same bottles for the same sample sites. Rinse out bottles (and caps) with warm tap water several times, then final rinse

with deionised water. If adhering films or deposits are evident, remove these with a clean bottlebrush, warm water and phosphate-free detergent such as Decon-90. In this instance, rinse bottles most thoroughly to remove all traces of detergent. If in doubt, obtain a new sample bottle.

- Replace caps on bottles, store in secure place, or put back into clean chilly bins for next period of use.
- Place all laboratory work sheets and field data sheets into designated storage folders or filing facility.

Additional notes

- 1-litre sample bottles. New bottles should be acid washed with 15% v/v HCl solution, rinsed thoroughly with tap water, then deionised water, and stored filled with deionised water until time of use.
- Sub-containers. Disposable 100–200-ml screw-top plastic bottles. Bottles and caps should preferably be rinsed with tap water, then deionised water, just before use to remove possible contaminants such as dust or atmospheric ammonia. Acid washing of these is not considered essential, but some check analyses for DRP absorption (which may occur on some plastics) should be carried out using a low-level P standard.
- Contamination (especially nutrient samples). Inadvertent contamination of the sample may occur at any stage of processing. Be cautious of water drops from wet hands or cross-contamination with pH electrode or during the filtration process (such as insufficient rinsing of filter and filter apparatus with deionised water between samples). Atmospheric ammonia contamination may be a problem in some laboratories and special measures may need to be taken to minimise this.
- Labelling. Use a spirit-based marker pen (preferably black) for all labelling of sample bottles and sub-containers. Along with the laboratory identification number, consider including an abbreviated site location, date, time and depth of sampling. Distinguish filtered and unfiltered sub-containers with “Filt” and “Unfilt” labels.

Appendix 3: Data management and processing using LakeWatch

LakeWatch is a computer program developed by Knowlysis Ltd for the analysis of lake monitoring data. A version of the program has been especially designed for New Zealand containing the New Zealand TLI equations (chapter 1, equations 1–4).

For information, contact:

Lakes Consulting: Noel Burns
Lakes Consulting
PO Box 161
Pauanui 2850
New Zealand.
Email: lakescon@xtra.co.nz
Phone and fax: +64 7 864 7449

Knowlysis Ltd: PO Box 90-058 AMSC
Auckland
New Zealand.
Email: lakewatch@knowlysis.co.nz
Phone: +64 9 358 0017
Fax: +64 9 358 3534