State of the environment monitoring of Lake Rotorangi: water quality and biological programme Annual Report 2011-2012

Technical Report 2012-08

ISSN: 0114-8184 (Print)
ISSN: 1178-1467 (Online)
Document: 1102000 (Word)
Document: 1141734 (Pdf)

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August 2012

Executive summary

Consents 0488 and 0489, originally granted to Egmont Electricity Ltd (then held by Powerco Ltd and more recently transferred to TrustPower Ltd) for the Patea Dam, required water quality and biological monitoring of Lake Rotorangi and lake level monitoring. At the time of granting the consents (1978) a Tribunal recognised that a recreational lake resource of regional importance would be formed but at the same time the potential existed for a range of adverse environmental impacts to occur. Monitoring programmes and reports had continued since 1984. The report covering the 2010-2011 period (the twenty-first annual report) was the final report in this format, with subsequent lake water quality monitoring reported as a state of the environment annual report, in part financed by TrustPower.

The consent holder lodged renewal applications in late 2007. The renewal process which continued through the 2008-2009 period, culminated in a formal hearing in June 2009 followed by appeals with subsequent, on-going, mediation during 2009-2010. The new consents became operative in mid December 2010 with considerable changes in conditions and associated monitoring requirements.

A NIWA consultant's report concerning trends in Lake Rotorangi water quality, commissioned by Council during the 1995-96 monitoring year, confirmed earlier monitoring reports' conclusions and identified minor adjustments and additions to future programmes to enable long term trend monitoring to be performed in accordance with State of the Environment monitoring requirements. The 2011-2012 programme continued to incorporate these changes. A later consultant's report (in 2000) re-confirmed trends (using up-dated methodology) that the lake was phosphorus limited and remained mesotrophic. Further trend reporting for the period 1990-2006 was provided as a component of the consents renewal process and suggested that while there has been a very slow rate of increase in trophic level, the lake would be classified as mesotrophic in terms of its biological condition. An update of the trend report (for the period 1990-2011) confirmed this very slow, insignificant rate of increase in trophic level.

Four water quality sampling surveys were performed during the 2011-2012 period, three of which followed several recent freshes in the catchment which impacted on aspects of water clarity along the lake.

Lake condition, in terms of lake productivity, continued to be within the category of mesotrophic to possibly mildly eutrophic (mildly nutrient enriched). However, taking into account the influence of suspended silt in this reservoir, and the reduced chlorophyll levels, the classification is more appropriately mesotrophic.

Thermal stratification was recorded during late summer - autumn at the mid and lower lake sites, with dissolved oxygen depletion measured in the lower waters of the hypolimnion at these two sites (anoxia in the middle and depletion in the lower reaches of the lake). Oxygen depletion continued into winter at the lower lake site. Lake overturn had not occurred completely at the lower lake site by the time of the winter survey although water temperatures were uniform throughout the water column. However, overturn was apparent at the mid lake site in winter. These conditions have been typical of this reservoir-type lake to date.

Throughout the monitoring year phytoplankton densities were moderate to low. The main limiting factors for communities within the lake probably continue to be plant nutrient availability and frequency of river freshes. A very sparse macroinvertebrate fauna was found amongst the fine sediments of the deeper lake sites where only those taxa able to tolerate lengthy periods of very low dissolved oxygen levels have been recorded.

The summer 2012 macrophyte survey identified the oxygen weed *Egeria densa* as the dominant macrophyte throughout the majority of the lake. Only two other species were recorded as dominant in particular areas, being *Lagarosiphon major* and *Ceratophyllum demersum* (hornwort). This is the first record of hornwort in Lake Rotorangi, and in addition to those species recorded by the Taranaki Regional Council, an additional three new species were recorded by NIWA in April 2012 when commissioned by TrustPower to assess the hornwort community. It is unlikely that these other species will ever become abundant. Hornwort on the other hand is considered highly invasive, and is expected to eventually become dominant, out-competing *E. densa* and *L. major*. While this is not expected to cause significant impacts on the ecology of Lake Rotorangi or on the hydroelectric scheme, there is now greater potential for it to spread to nearby lakes, where such impacts could be much more severe e.g. Lake Rotokare. This may be the subject of further investigation by the Taranaki Regional Council. The next survey is due to be performed in the 2014-2015 period.

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1. Introduction

1.1 General

Consents 0488 and 0489, originally granted to Egmont Electricity Ltd (then held by Powerco Ltd and later transferred to TrustPower Ltd) for the Patea Dam, required water quality and biological monitoring of Lake Rotorangi and lake level monitoring. At the time of granting the consents (1978) a Tribunal recognised that a recreational lake resource of regional importance would be formed but at the same time the potential existed for a range of adverse environmental impacts to occur. Monitoring programmes and reports had continued since 1984, with the report covering the 2010-2011 period (the twenty-first annual report) being the final report in this format. When consents 0488 and 0489 were renewed, included was a requirement that monitoring of the lake would be undertaken every three years. As a result, lake water quality monitoring is now undertaken as an annual state of the environment monitoring programme, on a cost share basis with TrustPower. The current, and every third survey hereafter, will also be reported in a separate document as required by consent 0489 and the associated Patea Hydro Electric Power Scheme - aquatic monitoring plan.

The Resource Management Act 1991 ('the RMA') established new requirements for local authorities to undertake environmental monitoring. Section 35 of the RMA requires local authorities to monitor, among other things, the state of the environment of their region or district, to the extent that is appropriate to enable them to effectively carry out their functions under the Act.

To this effect, the Taranaki Regional Council ('the Council') established a state of the environment monitoring ('SEM') programme for the region. This programme is outlined in the Council's 'State of the Environment Monitoring Procedures Document', which was prepared in 1997. The monitoring programme is based on the significant resource management issues that were identified in the Council's Regional Policy Statement for Taranaki (1994a).

The SEM programme is comprised of a number of individual monitoring activities, many of which are undertaken and managed on an annual basis (from 1 July to 30 June). For these annual monitoring activities, summary reports are produced following the end of each monitoring year. Where possible, individual consent monitoring programmes have been integrated with the SEM programme to save duplication of effort and minimise costs (as in the case of the TrustPower Ltd Patea Dam HEP programme in the past). The purpose of annual SEM reports is to summarise monitoring activity results for the year and provide a brief interpretation of these results.

Annual SEM reports act as 'building blocks' towards the preparation of the regional state of the environment report every five years. The Council's first, or baseline, state of the environment report was prepared in 1996 (TRC, 1996a), summarising the region's progress in managing environmental quality in Taranaki over the past two decades. The second report (for the period 1995-2000) was published in 2003 (TRC, 2003a). The third State of the Environment report (for the period 1995 to 2007) has also been published (TRC, 2009a) and includes trend reporting. The provision of appropriate computer software statistical procedures now allows regular reporting on trends in the environmental quality over time, in relation to Council's on-going monitoring activities, now that there has been an accumulation of a comprehensive dataset of sufficient duration to permit a meaningful analysis of trends (i.e. minimum of 10 years).

1.2 Background

Lake Rotorangi was formed in May 1984 by the construction of an earth fill dam on the Patea River. The power scheme harnessed the flow of the Patea River to produce sufficient power for Egmont Electricity to meet approximately 60% of its consumer needs. During the process of obtaining planning consents, it was recognised that although a regionally significant recreational resource would be formed, considerable environmental impacts might also occur. Consequently, when planning and water right consents were granted, specific conditions were imposed upon water rights, which involved monitoring and otherwise studying the effects of the scheme on the environment, for the protection of the public interest.

The initial sampling programme was designed to keep a watching brief on lake water quality and productivity trends, in order to assess the way in which the new lake was settling down and its overall environmental consequences. The results of this intensive monitoring programme were published in the 'Lake Rotorangi - Monitoring a New Hydro Lake' (Taranaki Catchment Board, 1988) report.

The initial monitoring of the lake indicated that the lake was not grossly eutrophic as was initially predicted, but mildly eutrophic or mesotrophic. The initial monitoring also determined that the annual thermal stratification cycle, which the lake undergoes, is the single most important factor influencing the overall water quality and biological productivity trends within the lake. The formation of a stable stratified lake during the spring/summer period is dependent upon seasonal ambient temperature changes. Stratification gives rise to a physical barrier, separating the surface water body (epilimnion) from the bottom water body (hypolimnion). The intermediary zone is known as the metalimnion. The characteristics of lakes and the importance of nutrients and eutrophication were fully discussed in the Taranaki Catchment Board (1988) report.

The appearance of Lake Rotorangi, its biological value, and its suitability for a range of recreational and commercial uses is directly related to lake water quality. Water quality management is therefore the key to the continued success of the lake and environs as regional and national recreational resources. Consequently, all lake management decisions and lake uses need to be undertaken in consideration of maintaining good lake water quality conditions.

Following the publication of the initial monitoring report, the Board in conjunction with the Egmont Electric Power Board considered the frequency and nature of the future monitoring programme for Lake Rotorangi. Given the unexpectedly favourable way in which the lake has settled down, it was therefore decided that the monitoring programme should be scaled down to a residual level involving less frequent sampling, yet be capable of maintaining an on-going measure of lake conditions. These scaled down programmes have now operated since 1988 and have been the subject of twenty-one Annual Reports. An opportunity was also taken (in mid 1995) to review the appropriateness of the monitoring programme and the results obtained over the seven years of its operation in this format. NIWA (as consultant to the Regional Council) provided the assessment and suggested minor changes to the monitoring programme to enable additional long term seasonal trend analysis to be performed, providing a more powerful capability for determining possible changes in tropic condition in the lake (Burns, 1995). An additional review of the results of the ten years of monitoring was undertaken by Lakes Consultancy (Burns, 1999) who also assessed the trophic status of Lake Rotorangi (see Section 1.4). Lake water quality trends for the period 1990 – 2006 were also re-analysed by Lakes Consultancy (Burns, 2006) as a component of the consent renewal process which was progressed during the 2007-2010 period. Taranaki Regional Council subsequently has re-analysed the water quality trends over the 1990-2011 period and will continue to update these trends at regular intervals.

There was concern for the impact that larger flood events could have on the lake during the summer stratification period. The original intensive monitoring period had been conspicuous for the absence of any large flood events entering the lake during such periods. However, the large floods of March 1990 provided some information in this respect (TRC, 1990). The impacts of minor freshes have been reported from time-to-time (TRC 1992; TRC 1993; TRC 1995).

As at June 2012, some 190 riparian plans have been prepared by the TRC within the Patea River sub-catchment and two plans in the Mangaehu River sub-catchment upstream of the lake. Within these plans some 637km of Patea streambanks [58% of the total banks' length] and 9.0km of Mangaehu stream banks [62%] currently have adequate riparian protection provided on the dairying properties covered by the plans. This represents increases of 19km and 2km in these two sub-catchments over the past year. Outside of the properties covered by plans there are a further 57% and 99% of streambanks in the Patea and Mangaehu catchments respectively, with only some (natural) degree of riparian protection, or landowner fencing/planting that is not covered by a Council-prepared plan. No riparian plans have, as yet, been prepared for properties in these reaches. Within the Patea River sub-catchment, the areas where there is an absence of riparian plans are located to the northeast and south east of the catchment, and comprise run-off or sheep and beef grazing properties rather than dairy farms. The Mangaehu catchment is predominantly hill-country grazing rather than dairy country.

1.3 Trends in lake water quality

As referenced in Section 1.2, Council provided the results and reports of seven years' (1988 to 1995) monitoring data to NIWA to assess trends in lake water quality. The report provided by NIWA (Burns, 1995) concluded that the lake was riverine in some aspects in that it can be substantially affected by flood events. Therefore the data need not necessarily be de-seasonalised before examination for trends with time. Analysis of the data showed that there had been few dramatic changes in water quality over the previous seven years with the lake remaining in a mesotrophic condition.

Minor changes to the existing monitoring programme (mainly standardisation of the four sampling dates) were recommended. These allowed for additional analysis of data, thus providing a powerful capability for the determination of any future change in the lake's trophic condition. These changes were incorporated into subsequent monitoring programmes.

An updated evaluation of the trophic status of the lake based upon a lengthier period (ten years) of monitoring data (Burns, 1999 and Burns et al 2000) using the methods of Burns and Rutherford (1998), showed that Lake Rotorangi had not changed in trophic level since monitoring commenced in 1988. The report stated that the lake at the upstream site (L1) was basically riverine in character, while the lake near the dam had the characteristics of a mesotrophic lake containing surplus nitrate, but with phytoplankton growth limited by phosphorus availability. While hypolimnetic anoxic conditions frequently were encountered at site L2 (half way along the lake) and occasionally near the dam (site L3), there had been little evidence of anoxic regeneration of phosphorus into the water column from the bottom sediments.

A further water quality trend analysis covering sixteen years' data (1990-2006), was undertaken as a component of the consents renewal process (Burns, 2006). This indicated that while there had been a very slow increase in the trophic level, the biological state of the lake remained mesotrophic. Elevated trophic level indices were influenced by high turbidity values (due to fine suspended sediment), a characteristic of this river reservoir, and not a true indication of the lake's trophic status. Burns concluded that 'despite the apparently very slow rate of change in trophic level, the lake would benefit from increased riparian management initiatives in the upstream catchment.'

The most recent lake water quality trend analysis, performed by the TRC for the 21 year period 1990-2011 (see Appendix II) has continued to support the findings and conclusions of Burns, 2006. i.e. that the trophic level continues to increase at a very small, insignificant annual rate of change (0.02 $\pm$ 0.01 TLI units per year) and it notes that there are some insignificant increases in the average concentrations of key variables (secchi disc visibility, chlorophyll-a, total phosphorus, and total nitrogen), with a significant temporal increase in nitrates.

1.4 Monitoring programme

1.4.1 Introduction

The Lake Rotorangi monitoring programme consists of two primary components.

1.4.2 Lake Rotorangi physicochemical sampling

The Taranaki Regional Council undertook sampling of the lake at two sites along the lake on four (seasonal) occasions. The analytical parameters measured followed standard lake sampling protocols at intervals and sites determined by the agreed programme. The upper (riverine) site was removed from the programme during the 2010-2011 period as it was not considered to be a representative lake site deemed necessary for future lake monitoring and state of the environment trending requirements.

1.4.3 Lake Rotorangi biological monitoring

Phytoplankton monitoring was performed at the two sites on each lake sampling visit (in conjunction with physicochemical sampling). Macroinvertebrate samples were collected from the substrate of the two sites during the spring physicochemical survey. The repeat of the aquatic macrophyte survey of the lake last performed during early February 2008 was undertaken in autumn 2012.

1.5 Objective

The objective of this Annual Report is to present the results of the 2011-2012 physicochemical water quality and biological monitoring programmes and to consider these results in conjunction with existing information. This extends the database providing additional information on Lake Rotorangi which can be used for trend detection purposes and to assist with lake management and consent renewal consideration.

2. Water quality monitoring

2.1 Methods

The water quality physicochemical monitoring programme for Lake Rotorangi consisted principally of four sampling surveys timed to coincide with:

a) pre-stratification period (spring) conditions (near 20 October);
b) stable summer stratification conditions (near 20 February);
c) pre-overturn (later summer) conditions (within one month of (b), and near 20 March); and
d) post-overturn winter conditions (near 20 June).

The parameters measured at the two lake sites during each sampling survey are listed in Table 1 and routine lake sampling sites are shown in Figure 1.

Table 1 Water quality parameters measured at the two sampling sites

Parameter	Sampling site	
	Lake Site 2	Lake Site 3
GPS location	**1729856E 5626435N**	**1734948E 5621974N**
General site code	**LRT 000300**	**LRT 000450**
Depth profile[1] for		
- dissolved oxygen	X	X
- temperature	X	X
Point source[2] in the:		
(a) Surface, for	[LRT00S300]	[LRT00S450]
- dissolved oxygen	X	X
- secchi disc transparency	X	X
- black disc transparency	X	X
- conductivity	X	X
- turbidity	X	X
- suspended solids	X	X
- chlorophyll-a[3]	X	X
(b) Epilimnion, for:	[LRT00E300]	[LRT00E450]
- suspended solids	X	X
- total phosphorus	X	X
- dissolved reactive phosphorus	X	X
- nitrate-nitrogen	X	X
- ammoniacal-nitrogen	X	X
- pH	X	X
- conductivity	X	X
(c) Hypolimnion, for:	[LRT00H300]	[LRT00H450]
- total phosphorus	X	X
- dissolved reactive phosphorus	X	X
- nitrate-nitrogen	X	X
- ammoniacal-nitrogen	X	X
- total Kjeldahl nitrogen	X	X
- pH	X	X
- conductivity	X	X
(d) Sediment/water/interface[4]	[LRT00B300]	[LRT00B450]
- ammoniacal-nitrogen	X	X
- total phosphorus	X	X
- dissolved reactive phosphorus	X	X
- nitrite and nitrate nitrogen	X	X

Note: [1] *Depth profile sampling refers to taking discrete depth measurements*
[2] *Point source sampling refers to taking samples which reflect the water quality of a specific zone*
[3] *Chlorophyll-a collected through a column (= 2.5 x secchi disc transparency) ie depth integrated (at sites LRT00P300 & LRTOOP450))*
[4] *February and March only*

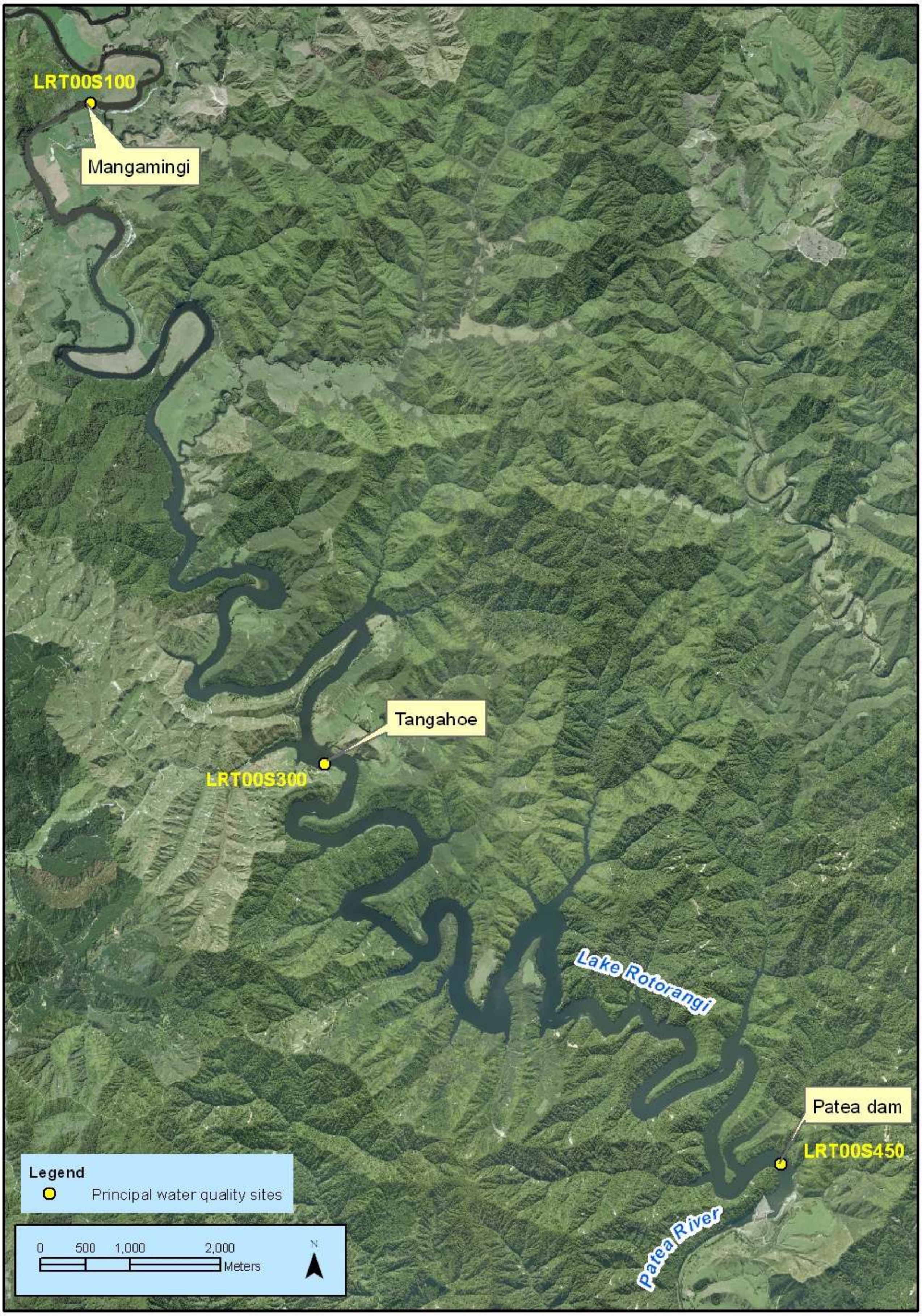


Figure 1 Aerial location map of Lake Rotorangi water quality sampling sites for 2011-2012 [LRT000300 and LRT000450].

In the year under review the sampling runs were performed at the established monitoring sites on the dates shown in Table 2.

Table 2 Sampling dates for the Lake Rotorangi water quality monitoring programme

Sampling Run	Time	Date
1	Spring	20 October 2011
2	Late summer, stratification	21 February 2012
3	Autumn, stratification	27 March 2012
4	Winter	22 June 2012

The spring sampling survey was performed under steady flood recession river flow conditions following six river freshes over the preceding three weeks (see Figures 2 and 3 and Appendix I). The late summer survey occurred under low river recession flow conditions following one small fresh (one week earlier) during the previous month. The autumn survey was performed under steady flood recession flow conditions two days after a fresh and within a month of seven freshes. The final (winter) survey was performed under steady flood recession river flow conditions one day after two moderate river freshes, four days after five moderate freshes, and after a wet period of eleven freshes in both catchments over the preceding six weeks. Lake level was moderately high (76.9 m asl) at the time of the spring survey and during the winter survey (77.3 m asl), moderately high (76.7 m asl) during the late summer survey, and very high (77.7 m asl) during the autumn survey.

Flow data for the Patea River, Mangaehu River and synthesised inflow to Lake Rotorangi are illustrated in Figures 2, 3 and 4 and attached as Appendix I. This synthetic flow is the flow entering the head of the lake (at Mangamingi) and equates to flows from the Patea River and Mangaehu River catchments above Mangamingi.

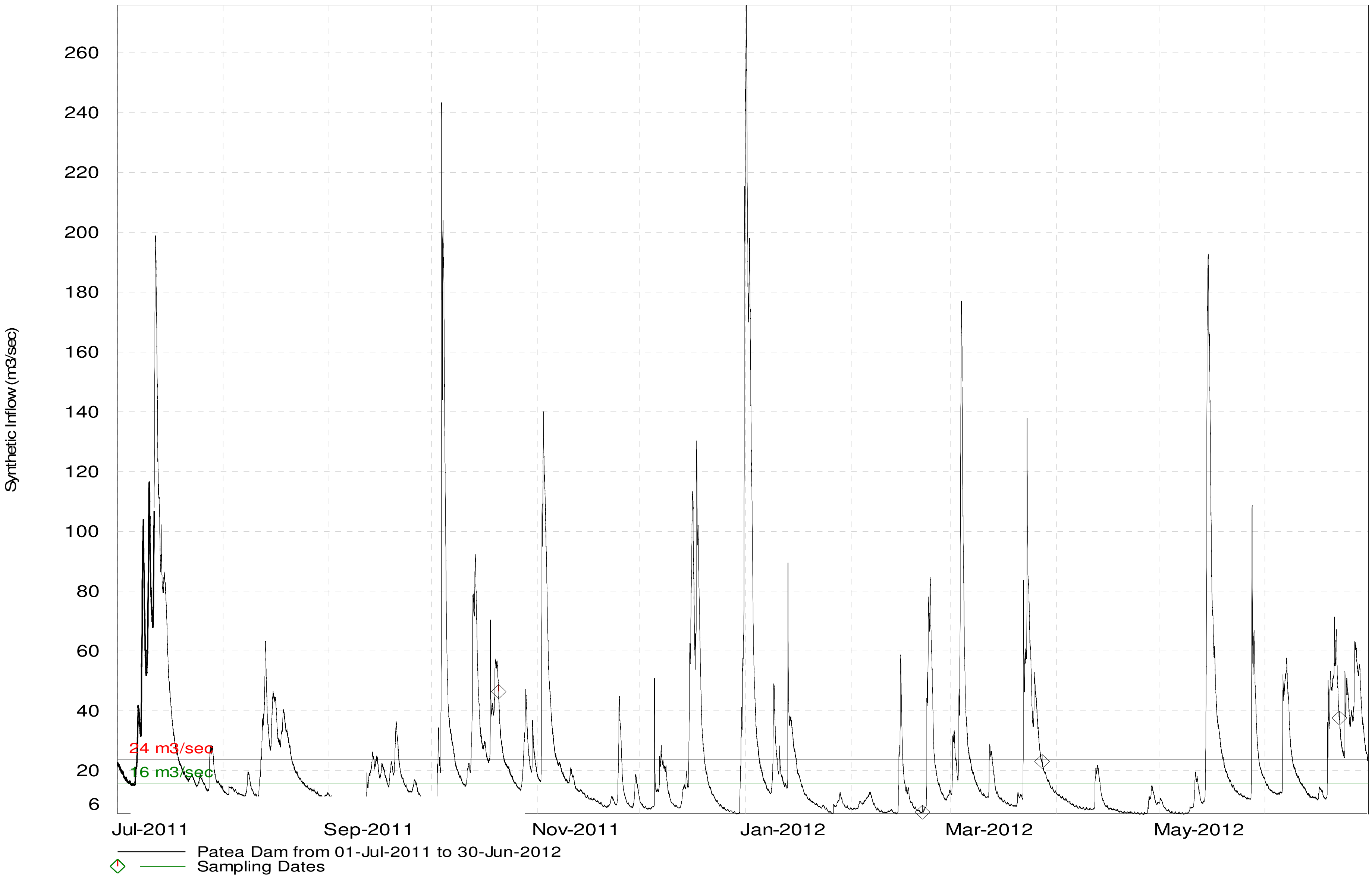


Figure 2 Synthesized hourly mean inflow at Lake Rotorangi for the period 1 July 2011 to 30 June 2012

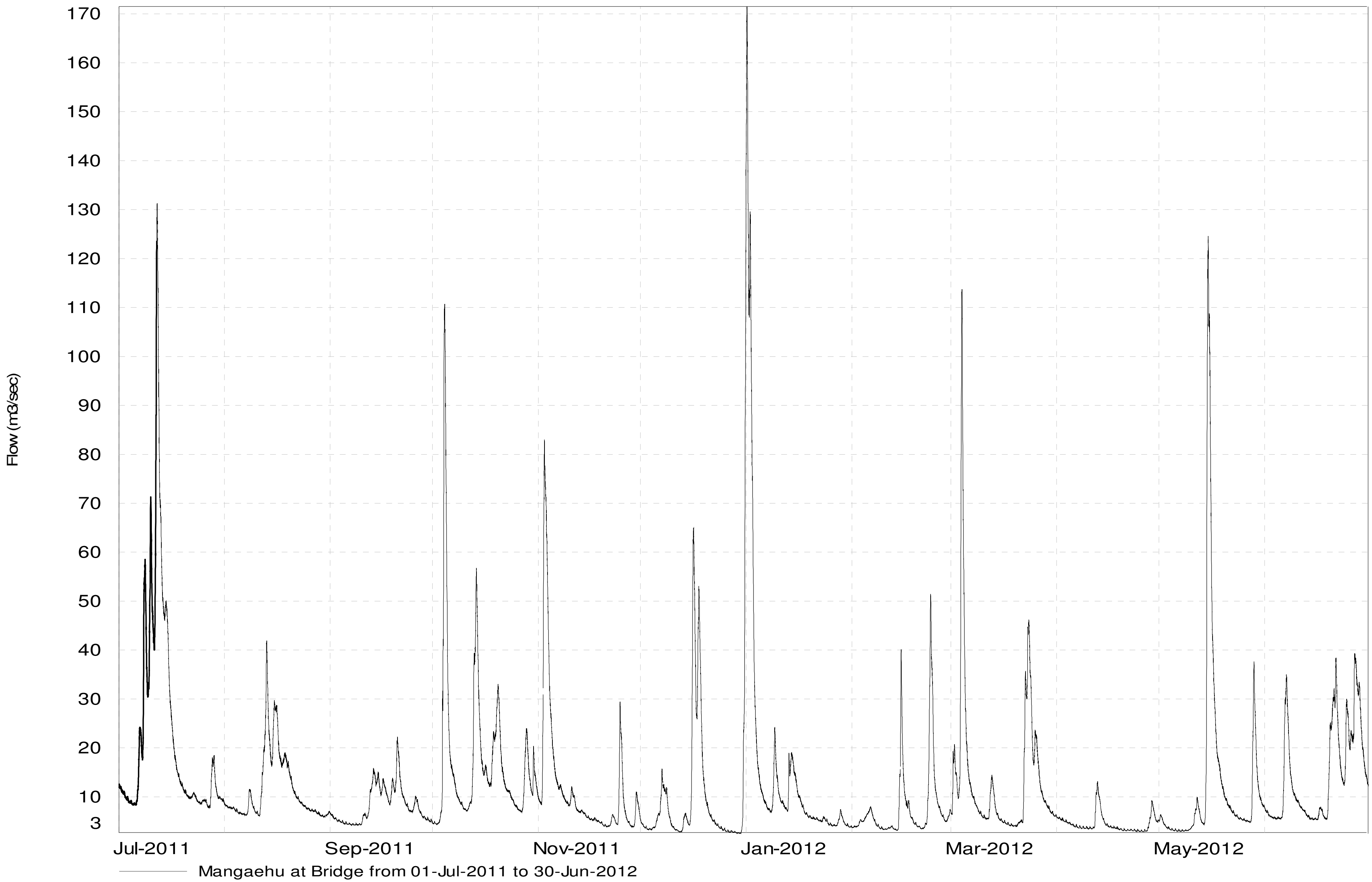


Figure 3 Flow in the Mangaehu River from July 2011 to June 2012

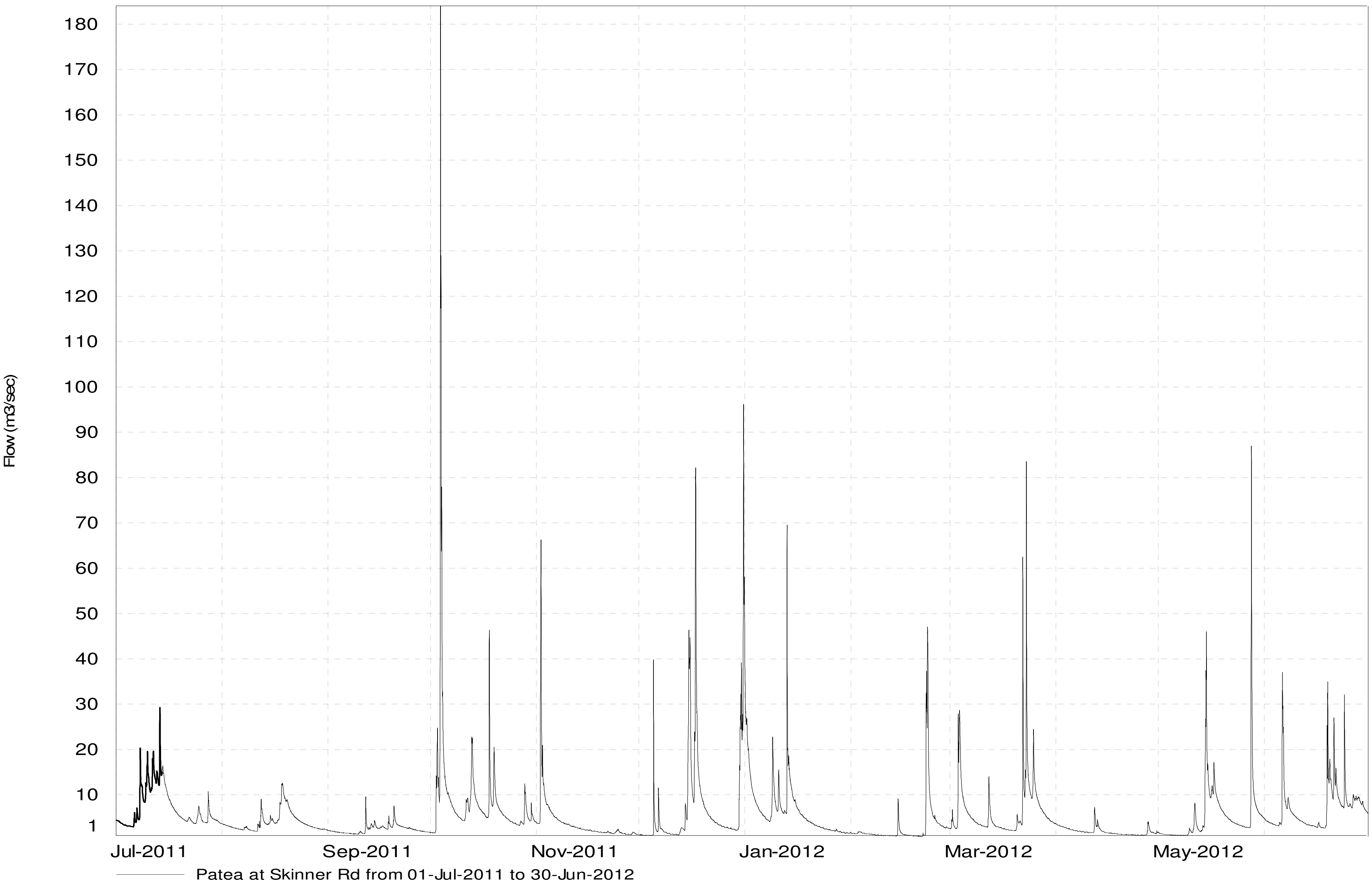


Figure 4 Flow in the Patea River at Skinner Road from July 2011 to June 2012

2.1.1 Results

2.1.1.1 General observations

Information recorded at each site on the four sampling occasions is summarised in Table 3. This information is collected in conjunction with physicochemical sampling data as a component of the monitoring programme. Lake conditions reflected the preceding river flow conditions referenced in Section 2.1.1.

Table 3 Observations at Lake Rotorangi monitoring sites on each sampling date during 2011-2012

Parameter											
Site	Date	Time	Staff Gauge	Weather	Wind	Air Temperature	Surface Water Temperature	Appearance	Secchi Disc transparency	Black Disc transparency	Depth at sampling site
Unit		(NZST)	(m)			(°C)	(°C)		(m)	(m)	(m)
L2	20.10.11	0900-0955	2.46	Partly cloudy, fine.	Mod S	13	14.2	Turbid, mid brown; surface chop; some debris	0.98	0.96	38
	21.02.12	0940-1040	-	Overcast, fine.	Calm	21	22.3	Clear, dark-green; surface flat; no debris	3.50	2.95	39
	27.03.12	0930-0945	3.20	Partly cloudy, fine.	Calm	13	16.9	Turbid, mid brown; surface flat; min. debris	2.04	1.44	40
	22.06.12	0930-1010	2.79	Overcast and misty, fine.	Calm	8	10.7	Slightly turbid, dark brown; surface flat; debris common	2.40	1.80	40
L3	20.10.11	1055-1155	-	Partly cloudy, fine.	Light SW	17	14.9	Discoloured, khaki; surface light chop, min debris	1.20	1.08	44
	21.02.12	1110-1205	-	Overcast, fine.	Light N	23.5	22.3	Clear, dark green; surface ripple; no debris	4.10	3.45	50
	27.03.12	1020-1135	-	Partly cloudy, fine.	Calm	20	17.5	Discoloured, dark green-brown; surface flat; min debris	2.70	2.65	42
	22.06.12	1050-1130	-	Partly cloudy, fine.	V. light NW	10	11.1	Discoloured, dark grey-green; surface flat; debris common	3.20	2.90	48

[Note: NR = not recorded; NATBD = not able to be determined; SG sited at Glen Nui ramp]

2.1.1.2 Thermal stratification

A summary of historical water temperature data is provided in Table 4.

Table 4 Statistical summary of surface water temperature data from June 1990 to June 2011

Location	Parameter	Unit	Minimum	Maximum	Median	N
L2 surface	Temperature	°C	9.4	23.9	17.5	82
L3 surface	Temperature	°C	9.5	24.6	17.7	82

The two lake sites (L2 and L3) continued to exhibit varying degrees of thermal stratification during the monitoring period (Figure 5) typical of the majority of past years' stratification patterns. Temperatures measured in the surface and bottom waters at each lake site, during the 2011-2012 period, are compared with the averages of all data (Table 5) for similar months prior to this year's sampling.

Table 5 Temporal changes in temperature (^{o}C) of surface and bottom waters at each Lake Rotorangi site (October 2011 to June 2012)

Sites	L2		L3	
Date	**Surface**	**Bottom**	**Surface**	**Bottom**
October 2011	14.2 (14.6)	8.5 (8.9)	14.9 (14.7)	8.3 (8.6)
February 2012	22.3 (21.7)	9.0 (9.7)	22.3 (22.1)	8.7 (9.4)
March 2012	16.9 (19.5)	9.1 (9.9)	17.5 (19.8)	8.8 (9.6)
June 2012	10.7 (11.2)	8.8 (9.3)	11.1 (11.2)	8.9 (9.4)

Note: *( ) = average monthly temperature for period 1984 to mid-2011*

All surface water temperatures at both sites were within past ranges measured at these sites (Table 4) and in the lake were generally within 1˚C of past monthly average temperatures at the time of all surveys, except the autumn survey when they were 2.3 to 2.6˚C below the corresponding monthly averages. Bottom water temperatures at both sites were lower but within 0.3˚C to 0.8˚C of corresponding monthly average temperatures throughout the year. These two sites' bottom water temperatures (8.3°C to 9.1°C) showed a very narrow range (0.8°C) due to minimal mixing through the year, while their surface water temperature ranges were much wider (11.6°C [L2] to 11.2°C [L3]).

Water temperature and dissolved oxygen profiles at each site are illustrated in Figure 5 for the four sampling occasions.

Partial thermal stratification was recorded at sites L2 and L3 at the time of the October 2011 survey (Figure 5). However both summer-autumn surveys illustrated well-established thermal stratification at these mid and lower lake sites, although this stratification was partially affected by floods between late summer and autumn. The location of the thermocline during summer was approximately 4 to 5 metres below the lake surface at both sites, but had lowered by the time of the autumn survey due to the influence of several freshes in the period between surveys. The occurrence of many significant freshes between mid May and the winter June 2012 survey, and cooling of epilimnetic waters, contributed to the complete destruction of temperature stratification at these sites by the time of the June 2012 survey, although a relatively strong dissolved oxygen stratification remained at site L3 at this time (see section 2.1.2.3), a similar situation to that monitored in many previous years.

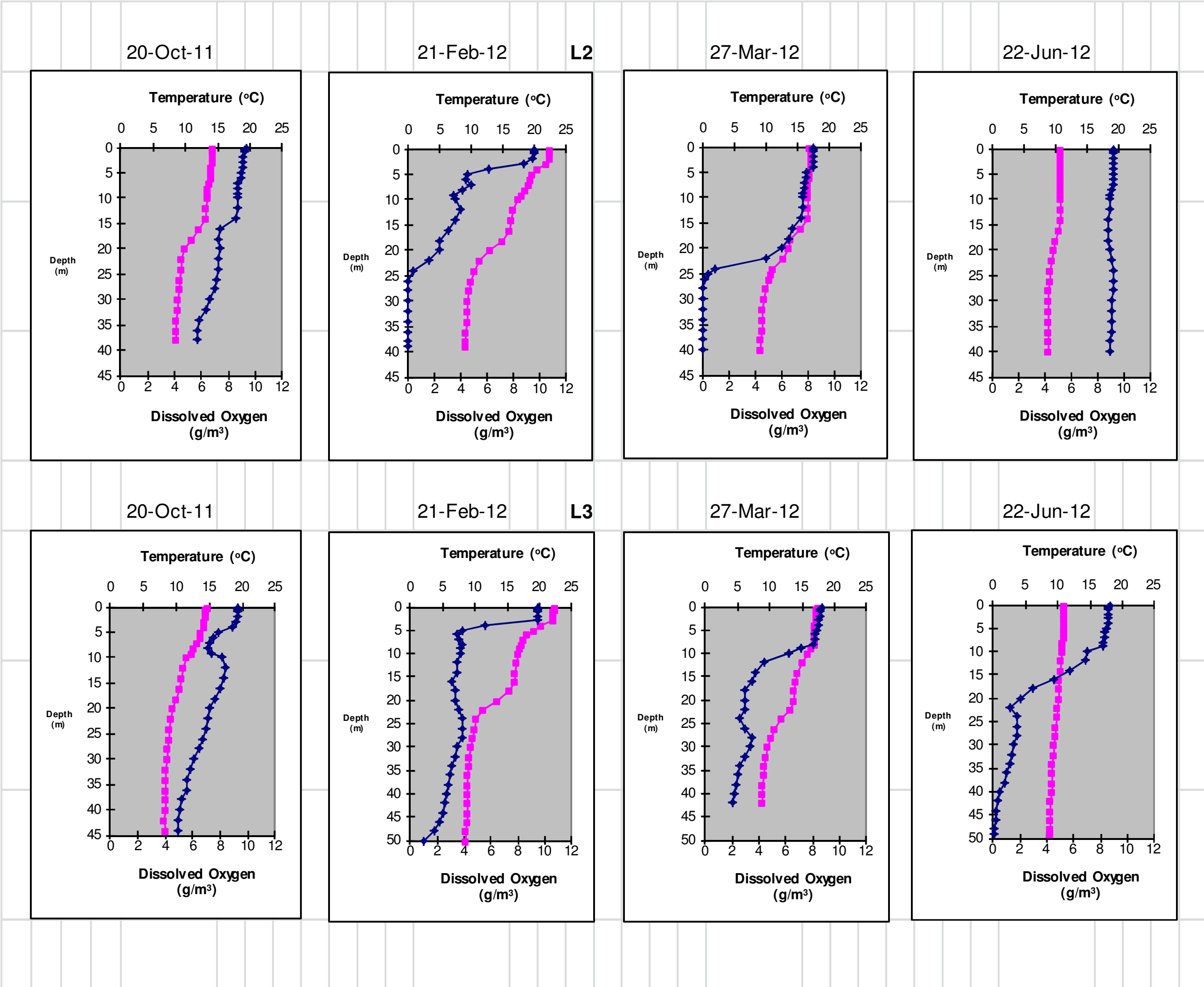
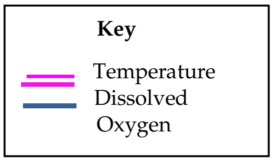


Figure 5 Temperature (˚C) and dissolved oxygen (g/m^3) profiles for site L2 and L3



2.1.1.3 Dissolved oxygen stratification

A summary of historical dissolved oxygen data is provided in Table 6.

Table 6 Statistical summary of dissolved oxygen data from June 1990 to June 2011

Location	Parameter	Unit	Minimum	Maximum	Median	N
L2 surface	Dissolved oxygen	g/m^3	6.8	11.1	8.8	82
	Dissolved oxygen saturation	%	68	116	91	82
L3 surface	Dissolved oxygen	g/m^3	3.6	10.7	8.8	82
	Dissolved oxygen saturation	%	34	116	95	82

Table 7 Temporal changes in percentage dissolved oxygen saturation in surface and bottom waters at each Lake Rotorangi site (October 2011 to June 2012)

Sites	L2		L3	
Date	**Surface**	**Bottom**	**Surface**	**Bottom**
October 2011	92 (93)	49 (29)	93 (96)	42 (33)
February 2012	112 (95)	0 (2)	109 (100)	9 (7)
March 2012	87 (92)	0 (5)	91 (93)	17 (6)
June 2012	83 (80)	77 (52)	79 (62)	1 (12)

Note: ( ) = average monthly saturation for period 1984 to mid-2011

Surface water percentage dissolved oxygen saturation levels were within past ranges at both sites during the monitoring year (Table 7). Levels varied in relation to average saturation levels recorded from previous monitoring surveys for the four relevant months. Surface levels were within 13% of total saturation with the exception of the winter, partial overturn level which fell to 83% saturation at site L2 and 79% saturation at site L3. The level was also slightly below the saturation normally found at the time of the autumn survey at both sites. Partial mixing of relatively highly saturated surface waters with the poorer quality hypolimnetic waters was recorded by the mid winter monitoring in June 2012.

Bottom water saturation levels varied according to the degree of stratification established in the lake at the time of sampling. Oxygen consumed by either biological or chemical processes cannot be replaced due to thermal separation from the more oxygenated surface waters. This causes depletion within the bottom waters unless re-mixing occurs, generally as a result of natural overturn (during cooler months) or river flooding. The deeper mid and lower lake sampling sites (L2 and L3) displayed lengthy periods of significant dissolved oxygen reduction (Figure 5) in the hypolimnetic lake waters during the survey period, but to a slightly lesser degree at the times of the spring survey and also the winter survey at site L2.

Total dissolved oxygen depletion was recorded within the hypolimnion during the February and March 2012 surveys at the mid lake site (L2) while the lower lake site L3 did not record total depletion at these times but reached total depletion below a depth of 40 metres in winter as has occurred from time to time in the past (see TRC, 2008). Some depletion was found at both sites in spring. During the late summer-autumn period, anoxic conditions (i.e. dissolved oxygen concentrations less than 0.5 g/m^3) were recorded at depths below 25 metres at site L2, but not at site L3.

Significant dissolved oxygen stratification remained at site L3 at the time of the winter survey despite minimal thermal stratification, a similar situation to that recorded at site L3 in seventeen of the previous eighteen years. Dissolved oxygen levels were below 2 g/m^3 and 1 g/m^3 in the lower lake waters of site L3 at the times of the autumn and winter surveys beyond 30 m depth respectively (Figure 5). There was no oxygen depletion at site L2 in winter, indicative of complete lake mixing, with levels of more than 8.5 g/m^3 recorded through the lake depth. It would have been anticipated that complete mixing of the lake waters at site L3 occurred within a short time after this winter survey as was the case in August, 2008 (see TRC, 2009).

Results from temperature/dissolved oxygen profiles at sites L2 and L3 for the February/March period have been used to calculate the gross volumetric hypolimnetic oxygen depletion rate (VHOD) and the area hypolimnetic oxygen depletion rate (AHOD) (Rutherford, 1982; Vant 1987). Due to destruction of stratification by extensive February 2004 flooding, these rates could not be determined for the 2003-2004 period, and partial destruction by frequent freshes in March 2012 invalidated such calculations for the 2011-2012 period.

The interpretation of hypolimnetic oxygen depletion rates in past years noted that there may be possible inaccuracies and shortcomings in the method of calculating VHOD and AHOD for the reasons referenced in earlier reports (Taranaki Catchment Board, 1988 and 1989). These refer particularly to rates calculated for a monitoring year when only two surveys were performed, or more than a one month period elapsed between the surveys used to assess the gross hypolimnetic deoxygenating rate, or the surveys were performed outside of summer months.

Burns (1995) noted that the average hypolimnion temperature often decreased with time which is the opposite type of change to that seen in most lakes. It means that it is not possible to calculate the re-oxygenation which occurs when hypolimnion of the lake is warmed by the downward mixing of thermocline water. This observed drop in the hypolimnion temperature may have been due to the inflow of cooler water into the top levels of the hypolimnion or may have been the result of the hypolimnetic withdrawal of water for power generation, although the latter is relatively unlikely. The observation of decreasing hypolimnion temperatures indicates that the water mass being monitored has changed, and this largely invalidates any reliable calculation of dissolved oxygen depletion rates. Further, it was noted that dissolved oxygen values close to the lake bottom were often near zero in February and March, which again weakened the value of calculated oxygen depletion rates. Also depletion rates should not be calculated when oxygen concentrations drop below 2 g/m^3 because depletion rates become concentration-dependent below this concentration (Burns 1995). Burns suggested that average hypolimnetic dissolved oxygen concentrations for each site (L2 and L3) should be plotted on time trend graphs for each month (February and March) on an annual basis. These data have been re-calculated and are presented in Table 8 and are presented graphically in the trends reports attached as Appendix II.

Table 8 Temporal changes in summer volumetric hypolimnetic oxygen depletion rate (VHOD: mg/m^3/d) for sites L2 and L3 in Lake Rotorangi [1990 to 2012]

Period	Sites	
	L2	L3
January to February 1990	-39.0	47.0
February to March 1991	4.7	17.1
January to February 1992	5.7	14.7
February to March 1993	-11.8	9.0
January to February 1994	-	17.5
January to February 1995	27.9	47.0
February to March 1996	9.5	49.7
February to March 1997	-	31.8
February to March 1998	-0.7	13.2
February to March 1999	-6.4	27.3
February to March 2000	5.4	5.7
February to March 2001	-1.1	30.4
February to March 2002	1.5	17.9
February to March 2003	-	-
February to March 2004	N/A	N/A
February to March 2005	20.7	58.7
February to March 2006	20.4	19.4
February to March 2007	5.9	4.3
February to March 2008	-6.7	16.7
February to March 2009	-9.3	29.9
February to March 2010	-22.3	-16.5
February to March 2011	9.2	-
February to March 2012	N/A	N/A
Average	0.8	26.6
Standardised at:	10.2˚C	9.8˚C

[Note: N/A = not applicable due to destratification caused by significant flooding]

Gross VHOD is the rate of dissolved oxygen concentration decrease in the hypolimnion of a stratified lake in which the water temperature has essentially remained constant (within an average hypolimnetic temperature difference no greater than 0.2°C at each site between sampling dates). Since VHOD rates vary with temperature, the rates have been standardised to typical hypolimnetic water temperatures for each of the two sites (10.2°C at L2 and 9.8°C at L3).

During the period from 1990 to 1994, VHOD rates generally appeared to have stabilised below 40 mg/m^3/d at both of the deeper lake sites, a range consistent with rates for mesotrophic lakes. The slightly increased hypolimnetic oxygen depletion rates measured at both sites but particularly at site L3 during the summers of January-February 1995, and February-March 1996, 1997, 2001, 2005, and 2011 were probably not indicative of any degradation in the state of the lake, but were more likely to have been due to the particularly warm, dry summers experienced during these periods resulting in less downward mixing of oxygen through the water column (Burns, 1995). Rates since the 1997-1998 summer period usually were consistent with rates for mesotrophic lakes. Burns (2006) noted that VHOD rates had been very variable over the 1990-2006 period due to vertical turbulence (provided by wide ranges of inflows) in this reservoir-type lake system and therefore were unlikely to provide useful trend information (see Figures in Appendix II; TRC 2009).

2.1.1.4 Secchi disc transparency/suspended solids

A summary of historical data is provided in Table 9.

Table 9 Statistical summary of physical water quality data from 1990 to June 2011

Location	Parameter	Unit	Minimum	Maximum	Median	N
L2 Surface	Secchi disc transparency	m	0.09	5.23	2.70	83
	Black disc transparency	m	0.09	4.50	2.20	75
	Turbidity	NTU	0.4	80	1.6	68
	Suspended solids	NTU	<2	83	2	76
	Conductivity @ 20°C	g/m³	5.4	15.0	10.9	65
L2 Epilimnion	Turbidity	mS/m	0.6	90	1.9	73
	Suspended solids	g/m³	<2	81	2	80
	Conductivity @ 20°C	mS/m	5.3	14.5	11.1	77
L2 Hypolimnion	Turbidity	NTU	1.6	230	4.9	76
	Suspended solids	g/m³	<2	310	3	82
	Conductivity @ 20°C	mS/m	7.8	13.5	10.6	80
L3 Surface	Secchi disc transparency	m	0.26	7.00	3.10	83
	Black disc transparency	m	0.23	5.25	2.70	71
	Turbidity	NTU	0.5	30	1.4	70
	Suspended solids	g/m³	<2	25	2	77
	Conductivity @ 20°C	mS/m	6.2	15.2	10.6	67
L3 Epilimnion	Turbidity	NTU	0.5	31	1.5	73
	Suspended solids	g/m³	<2	26	2	81
	Conductivity @ 20°C	mS/m	6.2	15.0	10.7	77
L3 Hypolimnion	Turbidity	NTU	0.8	65	2.8	75
	Suspended solids	g/m³	<2	89	2	83
	Conductivity @ 20°C	mS/m	6.2	12.4	10.3	79

Data recorded from each site during the 2011-2012 year (Table 10) were within ranges of previous results, with the secchi disc transparencies at all sites worse than median values on three occasions and suspended solids and turbidities near to or above median values on these same three occasions due to the proximity of preceding freshes.

The recession from floods prior to the spring sampling survey in particular caused some elevation in turbidity levels and reduced the secchi disc clarity recorded at both sites (Table 10).

Table 10 Physical water quality monitoring data for the two Lake Rotorangi sites in the 2011-2012 period

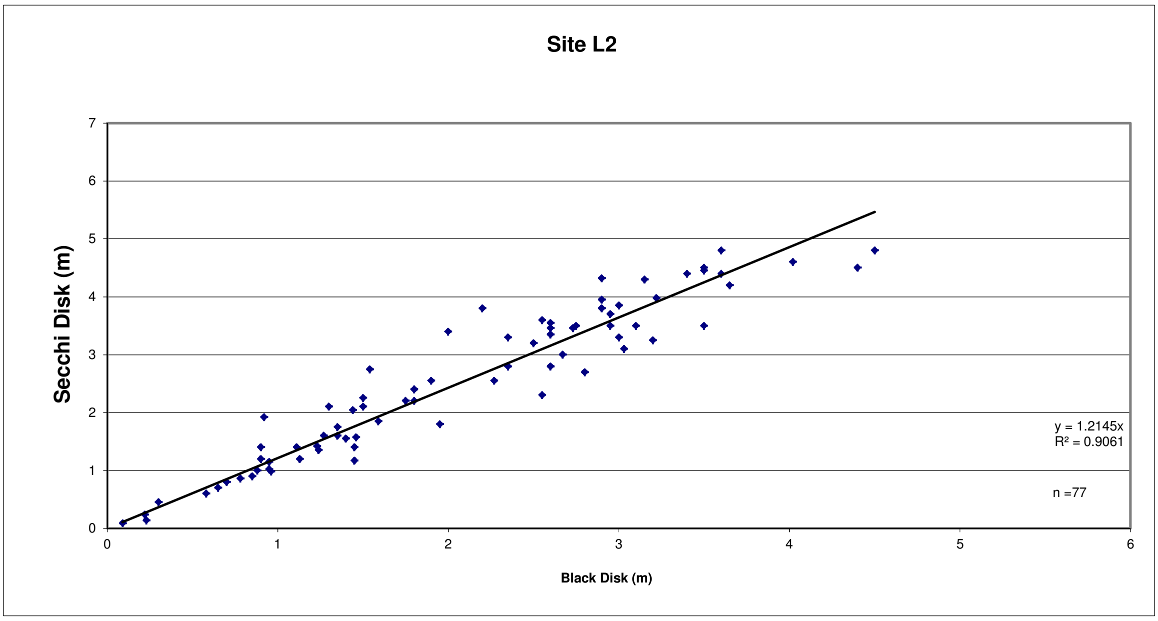
	Sites		L2			L3		
Date	**Parameter**	**Unit**	**S**	**E**	**H**	**S**	**E**	**H**
20.10.11	Secchi disc	m	0.98	-	-	1.08	-	-
	Turbidity	NTU	5.3	5.3	5.2	5.0	5.0	3.4
	Suspended solids	g/m³	5	5	5	4	4	2
	Conductivity @ 20°C	mS/m	8.9	8.7	10.1	8.0	8.0	10.4
21.02.12	Secchi disc	m	3.50	-	-	3.45	-	-
	Turbidity	NTU	1.0	1.4	3.0	0.7	0.8	1.7
	Suspended solids	g/m³	<2	<2	2	<2	<2	<2
	Conductivity @ 20°C	mS/m	-	12.9	10.7	11.0	10.8	10.3
27.03.12	Secchi disc	m	2.04	-	-	2.65	-	-
	Turbidity	NTU	2.6	2.9	8.8	1.4	1.6	3.0
	Suspended solids	g/m³	3	3	9	<2	<2	4
	Conductivity @ 20°C	mS/m	10.7	10.6	10.8	9.9	9.9	10.4
22.06.12	Secchi disc	m	2.48	-	-	2.90	-	-
	Turbidity	NTU	2.0	2.0	4.7	1.9	2.2	1.2
	Suspended solids	g/m³	<2	<2	4	<2	<2	<2
	Conductivity @ 20°C	mS/m	-	-	-	-	-	-
Range	Secchi disc	m	0.98-3.50	-	-	1.08-3.45	-	-
	Turbidity	NTU	1.0-5.3	1.4-5.3	3.0-8.8	0.7-5.0	0.8-5.0	1.2-3.4
	Suspended solids	g/m³	<2-5	<2-5	2-9	<2-4	<2-4	<2-4
	Conductivity @ 20°C	mS/m	(8.9-10.7)	(8.7-12.9)	(10.3-10.8)	(9.9-11.0)	(8.0-10.8)	(10.3-10.4)

Note: *[Sites: S = surface; E = epilimnion; H = hypolimnion; ( ) = limited data]*

The impacts of significant freshes resulted in particularly poor secchi disc clarity at sites L2 and L3 surface waters in spring (Table 10) with turbidity and suspended solids levels similar through the water column particularly at site L2.

Very similar ranges of secchi disc transparency levels were recorded at site L2 (0.98 to 3.50 metres) and site L3 (1.08 to 3.45 metres) during the monitoring year. Impacts of river freshes upon lake clarity through the water column were most marked in October 2012 due to several freshes preceding this survey, although not to the extent recorded on a number of occasions prior to this monitoring period.

Black disc transparency readings (Table 3) provide an estimate of horizontal water clarity, which is of value in the optical characterisation of water, and in relation to human recreational water use. Black disc observations in conjunction with vertical (secchi disc) readings provide information on the penetration of diffuse light into water. Pairs of observations will continue to be measured in Lake Rotorangi to provide a suitable database from which interpretations can be made at a later date. A correlation between secchi disc and black disc transparencies has been prepared for each of the three sampling sites (Figure 6). This indicates that a direct relationship exists between the two transparency readings, as might be expected, and that while in general secchi disc (vertical) clarity has been slightly greater than black disc (horizontal) clarity at both sites (by a ratio of about 1.2:1), the two transparencies' values are more similar further down the lake, i.e. where the river influence is less pronounced.



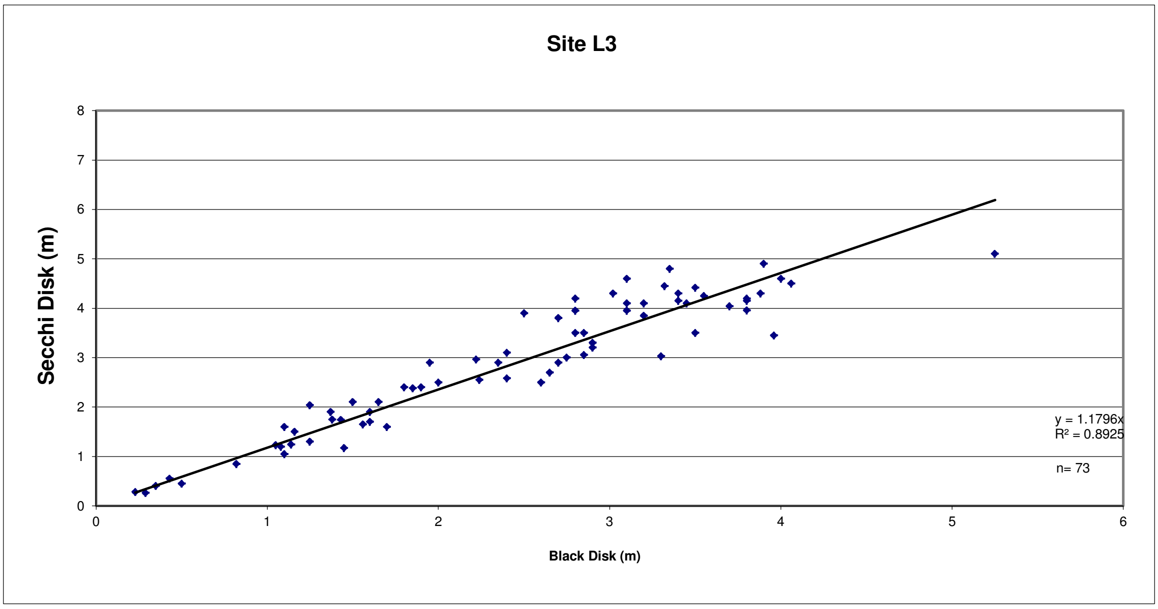


Figure 6 Relationship between secchi and black disc transparency at each sampling site

These trends have continued to be recorded during the most recent monitoring period under a moderate range of clarities. During the 2011-2012 monitoring period, black disc transparency ranges recorded at site L2 (0.96 to 2.95 metres) and L3 (1.08 to 3.45 metres) were relatively similar at both sites but never approached historical maxima due to the poorer clarity as a result of the effects of (often frequent) preceding river freshes.

2.1.1.5 Biological productivity

Primary lake productivity may be indicated from the measurement of chlorophyll-a concentrations (Pridmore, 1987). A summary of historical data is provided in Table 11.

Table 11 Statistical summary of chlorophyll-a data from 1990 to June 2011

Location	Parameter	Unit	Minimum	Maximum	Median	Mean	N
L2 photic zone	Chlorophyll-a	mg/m3	<1.0	13.9	2.6	3.1	82
L3 photic zone	Chlorophyll-a	mg/m3	<1.0	13.4	2.0	3.0	82

Results recorded during the monitoring programme are presented in Table 12 and a summary of yearly results in Table 13.

Table 12 Chlorophyll-a concentrations (mg/m^3) (including historical monthly means) for the Lake Rotorangi sites

Date	Sites			
	L2		L3	
	Mean (1984-2011)	Result 2011-12	Mean (1984-2011)	Result 2011-12
October 2011	3.7	2.6	3.6	4.7
February 2012	3.3	5.0	2.8	2.5
March 2012	3.7	3.6	3.8	5.8
June 2012	1.7	1.6	1.5	1.4
Range: 2011-2012	-	1.6-5.0	-	1.4-5.8
Range: 1984-2011	-	<1-13.9	-	<1-15

Table 13 Summary of past chlorophyll-a concentrations (mg/m^3) survey data for the two Lake Rotorangi sites (1984 to 2011)

	Sites					
	L2			L3		
Period	No. Results	Mean	Range	No. Results	Mean	Range
1984	8	1.8	<1 – 3.4	8	3.3	<1 – 8.3
1985	12	2.3	<1 – 5.7	12	3.3	1.6 – 7.4
1986	8	1.9	<1 – 4.0	11	2.9	<1 – 15
1987	9	3.7	<1 – 13	9	1.5	<1 – 5.4
1988-90	6	4.0	<1 – 7.2	6	3.5	<1 – 6.6
1991	4	1.9	<1 – 3.6	4	3.3	<1 – 6.3
1992	3	4.3	3.5 – 5.7	3	3.8	1.6 – 5.8
1993	3	2.5	1.2 – 4.6	3	1.5	1.0 – 2.2
1994	4	2.7	1.8 – 4.0	4	2.0	<1 – 3.6
1995	4	2.1	1.5 – 3.2	4	2.9	1.4 – 6.2
1996	4	3.0	<1 – 4.8	4	2.2	<1 – 5.2
1997	4	1.2	<1 – 2.0	4	1.9	<1 – 3.5
1998	4	2.5	<1 – 4.0	4	2.4	<1 – 6.7
1999	4	4.1	1.3 – 4.8	4	2.3	<1 – 4.2
2000	4	3.7	<1 – 8.3	4	1.9	<1 – 3.5
2001	4	2.4	1.1 – 5.0	4	2.4	1.1 – 4.3
2002	4	3.0	<1 – 5.6	4	4.6	<1 – 8.1
2003	4	1.5	<1 - 2.8	4	1.3	1.0 - 2.0
2004	4	3.1	<1-8.9	4	5.1	<1-13.4
2005	4	3.3	1.5-4.5	4	2.1	<1-4.2
2006	4	4.0	1.3-5.8	4	2.8	1.0-6.3
2007	4	5.3	<1-13.9	4	4.8	1.1-12.1
2008	4	2.2	1.6-2.7	4	2.4	1.2-4.6
2009	4	4.4	1.9-8.1	4	3.5	1.6-5.7
2010	4	4.4	<1-6.7	4	4.6	1.0-7.4
2011	4	3.5	<1-7.5	4	3.2	<1-5.2

All chlorophyll-a concentrations measured at the two sites were within past ranges (Table 11) found by surveys since 1990. Concentrations were higher than or equal with historical median values at site L2 on all but the winter survey occasion and at site L3 higher than the historical median on all but the winter survey occasion.

Maximum lake chlorophyll-a concentrations have tended to be measured during late summer or autumn at sites L2 and L3. Over the current period, the highest concentrations were found in the photic zone of the mid and lower lake in spring and late summer when concentrations were similar to, or well above, historical mean monthly results for each of these sites. All measured concentrations were within previous ranges recorded since 1984 at each site (Tables 12 and 13). The maximum chlorophyll-a concentration of 5.8 mg/m^3 was measured at lake site L3 during the autumn period but this was only 0.8 mg/m^3 higher than the concentration found at site L2 earlier in late summer (coincidental with a pH of 8.0 units).

Mean 2011 values at both sites were typical of ranges at each site for the sampling period from 1994 to 2010 where the average annual means have been 3.1 mg/m^3 for site L2 (range: 1.2 to 5.3 mg/m^3) and 2.9 mg/m^3 for site L3 (range: 1.3 to 5.1 mg/m^3).

In terms of broad guidelines listed in Pridmore (1987) for maximum and annual mean chlorophyll-a concentrations, the lake would continue to be most likely categorised as mesotrophic. This categorisation is consistent with the conclusions of Burns (1995, 1999, and 2006). However, these guidelines should be used with caution due to the variability of the sample monitoring particularly in earlier years and the riverine nature of this lake. It should also be emphasised that chlorophyll-a measurements are only partial indications of trophic state. Determination of trophic condition requires examinations of a number of diverse criteria, particularly nutrients, clarity, and chlorophyll-a (see Burns, 1999, Burns, 2006 and Appendix II).

2.1.1.6 Nutrients

A summary of historical nutrients data is provided in Table 14 with water quality data relating to nutrient species, measured during the monitoring period, summarised for each site in Tables 15 to 18. The results are discussed in relation to the epilimnion and hypolimnion of the lake.

Table 14 Statistical summary of nutrients data from 1990 to June 2011

Site	Parameter	Unit	Minimum	Maximum	Median	No. of samples
L2 Epilimnion	Dissolved reactive phosphorus	g/m³P	<0.003	0.018	0.005	81
	Total phosphorus	g/m³P	0.006	0.213	0.020	81
	Ammonia nitrogen	g/m³N	<0.003	0.370	0.020	81
	Nitrite	g/m³N	0.001	0.015	0.007	71
	Nitrate	g/m³N	<0.01	0.99	0.36	73
	Total Kjeldahl nitrogen	g/m³N	<0.01	1.20	0.29	78
	Total nitrogen	g/m³N	0.21	1.65	0.64	77
	pH		6.9	8.5	7.5	73
L2 Hypolimnion	Dissolved reactive phosphorus	g/m³P	<0.003	0.029	0.008	82
	Total phosphorus	g/m³P	0.011	0.22	0.022	82
	Ammonia nitrogen	g/m³N	<0.003	0.436	0.079	82
	Nitrite	g/m³N	<0.001	0.022	0.009	72
	Nitrate	g/m³N	0.02	0.93	0.50	76
	Total Kjeldahl nitrogen	g/m³N	0.04	0.96	0.30	81
	Total nitrogen	g/m³N	0.45	1.50	0.84	81
	pH		6.5	7.4	6.9	75
L3 Epilimnion	Dissolved reactive phosphorus	g/m³P	<0.003	0.023	0.004	81
	Total phosphorus	g/m³P	0.004	0.097	0.017	81
	Ammonia nitrogen	g/m³N	<0.003	0.140	0.013	81
	Nitrite	g/m³N	<0.001	0.020	0.005	71
	Nitrate	g/m³N	<0.01	0.83	0.36	73
	Total Kjeldahl nitrogen	g/m³N	<0.01	1.15	0.27	78
	Total nitrogen	g/m³N	0.22	1.51	0.65	77
	pH		6.6	8.7	7.6	73
L3 Hypolimnion	Dissolved reactive phosphorus	g/m³P	<0.003	0.026	0.006	81
	Total phosphorus	g/m³P	0.006	0.134	0.017	81
	Ammonia nitrogen	g/m³N	<0.003	0.170	0.007	81
	Nitrite	g/m³N	<0.001	0.020	0.001	71
	Nitrate	g/m³N	0.05	1.00	0.58	75
	Total Kjeldahl nitrogen	g/m³N	0.03	1.14	0.18	80
	Total nitrogen	g/m³N	0.30	1.78	0.76	80
	pH		6.6	7.2	6.8	75

Table 15 Nutrient water quality monitoring data for Lake Rotorangi site L2: Epilimnion

Parameter		Date			
	Unit	20 Oct 2011	21 Feb 2012	27 Mar 2012	22 Jun 2012
Sample Depth	m	3	3	3	3
Dissolved Reactive Phosphorus	g/m³P	0.009	<0.003	0.012	0.004
Total Phosphorus	g/m³P	0.051	0.043	0.059	0.041
Ammonia-N	g/m³N	0.046	0.016	0.065	0.047
Nitrite	g/m³N	0.009	0.004	0.008	0.013
Nitrate	g/m³N	0.40	0.13	0.39	0.60
TKN	g/m³N	0.25	0.20	0.24	0.16
Total nitrogen	g/m³N	0.66	0.33	0.64	0.76
pH		7.3	8.0	7.5	7.1

Table 16 Nutrient water quality monitoring data for Lake Rotorangi site L2: Hypolimnion

Parameter		Date			
	Unit	20 Oct 2011	21 Feb 2012	27 Mar 2012	22 Jun 2012
Sample Depth	m	34	34	36	36
Dissolved Reactive Phosphorus	g/m^3P	0.009	0.008	0.009	<0.003
Total Phosphorus	g/m^3P	0.032	0.034	0.044	0.038
Ammonia-N	g/m^3N	0.026	0.044	0.062	0.040
Nitrite	g/m^3N	0.006	0.003	0.003	0.009
Nitrate	g/m^3N	0.68	0.65	0.60	0.58
TKN	g/m^3N	0.09	0.13	0.06	0.17
Total nitrogen	g/m^3N	0.78	0.78	0.66	0.75
pH		6.9	6.7	6.7	7.1

Table 17 Nutrient water quality monitoring data for Lake Rotorangi site L3: Epilimnion

Parameter		Date			
	Unit	20 Oct 2011	21 Feb 2012	27 Mar 2012	22 Jun 2012
Sample Depth	m	3	3	3	3
Dissolved Reactive Phosphorus	g/m^3P	0.005	<0.003	<0.005	<0.003
Total Phosphorus	g/m^3P	0.044	0.019	0.024	0.031
Ammonia-N	g/m^3N	0.062	0.016	0.005	<0.003
Nitrite	g/m^3N	0.014	0.004	0.004	0.003
Nitrate	g/m^3N	0.55	0.28	0.36	0.52
TKN	g/m^3N	0.35	0.18	0.09	0.12
Total nitrogen	g/m^3N	0.91	0.46	0.45	0.64
pH		7.2	8.4	7.4	6.9

Table 18 Nutrient water quality monitoring data for Lake Rotorangi site L3: Hypolimnion

Parameter	Unit	Date			
		20 Oct 2011	21 Feb 2012	27 Mar 2012	22 Jun 2012
Sample Depth	m	38	38	36	44
Dissolved Reactive Phosphorus	g/m^3P	0.011	0.007	0.016	<0.003
Total Phosphorus	g/m^3P	0.024	0.016	0.020	0.017
Ammonia-N	g/m^3N	0.005	0.006	<0.003	<0.003
Nitrite	g/m^3N	0.002	<0.001	<0.001	<0.001
Nitrate	g/m^3N	0.74	0.73	0.65	0.56
TKN	g/m^3N	0.05	0.02	<0.01	0.05
Total nitrogen	g/m^3N	0.79	0.75	0.65	0.61
pH		6.9	6.8	6.6	6.5

2.1.1.6.1 Epilimnion

The nutrient concentrations of the epilimnetic waters of the main lake (sites L2 and L3) were again characterised by relatively low levels of available plant nutrients (Tables 15 and 17) on the majority of the monitoring occasions. In general the lowest concentrations of nutrients, such as TN and TP, were present when the lake waters were fully stratified (e.g. late summer, 2012). Total phosphorus concentrations have varied in the past in association with temporal and spatial fluctuations in suspended solids concentrations. These variations were apparent during the monitoring year but not over a large range as turbidities only varied over a relatively small range (about 4 NTU) in the 2011-2012 period.

Continuing the trend documented by previous monitoring programmes, there was a significant reduction in the readily available nutrient species (particularly nitrate-N) with lake stratification in late summer at sites L2 and L3, attributable to a possible increase in biological activity e.g. uptake by phytoplankton. pH levels were elevated at this time (8.0 to 8.4), consistent with a small increase in mid and lower lake sites' phytoplankton photosynthetic activity (e.g. up to 112% dissolved oxygen saturation of the surface waters). Partial mixing of the lake waters, plus the influence of river freshes, resulted in increases in certain nutrient concentrations and lower pH values (6.9 to 7.3) in spring 2011 and mid winter 2012 at mid and lower lake sites.

2.1.1.6.2 Hypolimnion

The onset of anoxic conditions in the hypolimnetic waters during stratification resulted in increases in ammonia-N levels (Tables 16 and 18) during the summer-autumn period at site L2, but not at site L3 where complete anoxia was not recorded over this period. Some decrease in nitrate-N concentration was recorded at site L3 in winter when the lake remained partly stratified. pH levels were consistently close to neutral (6.5 to 7.1 units), often significantly lower (by up to 1.6 pH units) than the pH of the surface waters and typical of the deeper waters of the hypolimnion particularly during periods of stratification. However, pH levels were identical (in the epilimnion and hypolimnion) at site L2 in winter when the lake was fully mixed.

The lengthy period of partial to complete stratification at sites L2 and L3 contributed to the variability in nutrient concentrations. The total phosphorus levels at sites L2 and L3 showed some variability in relation to small changes in turbidity, particularly in autumn 2012, caused by fine suspended sediment settling through the hypolimnetic waters.

2.1.1.6.3 Bottom of hypolimnion

In an addendum to the Burns (1995) report it was noted that dissolved oxygen concentrations close to the lake bottom were often near zero in February and March each year. Burns recommended that on these occasions additional samples should be collected from near the lake bottom (at sites L2 and L3) in order to determine whether this anoxia had caused the redox potential at the sediment-water interface to drop to a point whereby dissolved reactive phosphorus and/or ammonia had been released from the sediment.

Samples for this purpose have been collected at sites L2 and L3 in February and March of each monitoring year since 1996 during anoxic conditions at site L2 and usually approaching anoxia at site L3. A summary of historical data is provided in Table 19.

Table 19 Statistical summary of nutrients and related data in the lower hypolimnion in relation to comparative hypolimnetic data at sites L2 and L3 from 1996 to June 2011

Site	Location			Lower hypolimnion (near bed)			Hypolimnion			
	Parameter	Unit	N	Minimum	Maximum	Median	N	Minimum	Maximum	Median
L2	Dissolved reactive phosphorus	g/m^3P	31	<0.003	0.040	0.007	32	<0.003	0.017	0.008
	Total phosphorus	g/m^3P	31	0.012	0.276	0.022	32	0.011	0.220	0.020
	Ammonia nitrogen	g/m^3N	31	0.015	0.622	0.149	32	0.014	0.289	0.121
	Nitrate	g/m^3N	26	<0.01	0.70	0.38	32	0.02	0.70	0.42
	Temperature	°C	31	8.1	14.3	9.6	32	8.1	14.4	9.6
	Turbidity	NTU	31	2.4	310	9.5	32	1.6	230	4.2
	Dissolved oxygen	g/m^3	31	0	6.4	0	32	0	7.6	0
	pH		22	6.5	7.0	6.8	32	6.5	7.3	6.8
L3	Dissolved reactive phosphorus	g/m^3P	30	<0.003	0.032	0.008	32	<0.003	0.024	0.006
	Total phosphorus	g/m^3P	30	0.008	0.298	0.029	32	0.006	0.082	0.014
	Ammonia nitrogen	g/m^3N	30	<0.003	0.111	0.018	32	<0.003	0.064	0.007
	Nitrate	g/m^3N	26	0.12	0.69	0.55	32	0.17	0.78	0.59
	Temperature	°C	30	7.4	14.7	9.2	32	7.7	14.9	9.3
	Turbidity	NTU	29	1.0	140	15	32	0.9	65	2.0
	Dissolved oxygen	g/m^3P	30	0	3.5	0.4	32	0	4.8	1.4
	pH		20	6.6	7.0	6.8	32	6.6	7.1	6.8

Historical median data (1996-2011) indicate that the general trend for both sites (L2 and L3) has been a small increase in ammoniacal nitrogen and decrease in nitrate N in the hypolimnetic anoxic zone near the sediment interface. There was no significant change in phosphorus species at site L2 but some increase at site L3, particularly for total phosphorus, noting that a marked increase in turbidity was typical at this site nearer the sediment interface.

The nutrient analytical results from sampling in February and March 2012 are summarised in Table 20 and may be compared with results of samples collected from higher up the water column within the hypolimnion on the same occasions (Tables 16 and 18).

Table 20 Nutrient water quality monitoring data for Lake Rotorangi sites L2 and L3: lower hypolimnion (above the lake bed) in the 2011-2012 period

Site		L2		L3	
Parameter	**Unit**	**21 Feb 2012**	**27 Mar 2012**	**21 Feb 2012**	**27 Mar 2012**
Sample Depth	M	38	39	48	41
Dissolved Reactive Phosphorus	g/m^3P	0.008	0.009	0.006	0.007
Total Phosphorus	g/m^3P	0.027	0.036	0.019	0.015
Ammonia-N	g/m^3N	0.083	0.057	0.004	<0.003
Nitrate-N	g/m^3N	0.62	0.59	0.68	0.68
[Dissolved oxygen]	g/m^3	[0]	[0]	[1.4]	[2.1]
[Turbidity]	NTU	[3.8]	[11]	[2.9]	[1.9]
[pH]		[6.7]	[6.7]	[6.8]	[6.7]
[BOD_5]	g/m^3	-	2.2	-	<0.5
[COD]	g/m^3	-	8	-	7

[ ] = additional parameters

During the summer-autumn stratification period anoxic conditions were present in the lower hypolimnion at site L2 but only approached low levels at site L3 in February 2012 and March 2012 (see Figure 5). Site L2 showed no increases in dissolved reactive phosphorus on either survey occasion in the lower hypolimnetic waters near the sediment interface (Table 20) compared with higher in the water column of the hypolimnion (Table 16). Despite an increase in turbidity at site L2 in March 2012, the total phosphorus level also did not increase at this time. An increase in ammonia nitrogen (of 0.039 g/m^3N) in February 2012 was consistent with reducing conditions deep in the anoxic zone with some reduction in nitrate nitrogen concentrations on this survey occasion.

Differences in nutrient species between the deeper hypolimnetic waters and waters higher in the hypolimnion were more marked at site L3 during summer-autumn despite incomplete anoxia being recorded on both sampling occasions. No increases in ammonia nitrogen concentration were measured on either occasion when nitrate nitrogen concentrations were not significantly different. Total phosphorus did not increase significantly on either occasion when turbidities indicated minimal change in fine suspended sediment in the water near the lakebed.

All nutrient concentrations measured near the lake bed at sites L2 and L3 (Table 20) remained within the range of historical data (Table 19) measured previously during summer-autumn anoxic and near anoxic conditions.

Burns (2006) concluded that DRP and ammonia-N levels indicated a relative lack of nutrient release under anoxic conditions, consistent with lakebed sediment not yet contaminated with high nutrient levels.

Monitoring of the waters of the lower hypolimnion at sites L2 and L3 will be continued during February and March surveys as a component of the long-term monitoring programme.

2.1.1.6.4 General

Nutrient data surveyed during the 2011-2012 monitoring period were within ranges recorded since 1990 for all sites.

Nutrient data gathered over the 1990 to 2006 period have been analysed by a consultant (Burns, 2006) and by TRC for the 1990-2011 period (Appendix II), and indicate for the lacustrine (lake-like) sites L2 and L3, that total nitrogen (TKN plus nitrate) availability is surplus to phytoplankton requirements and that phosphorus is the growth-limiting nutrient. Phosphorus is reduced more than nitrogen by phytoplankton uptake and sedimentation while nitrates in the lake remain high. While TP and TN nutrients have shown non-significant temporal increases over the twenty year period, more significant temporal increases in DRP and nitrate-N are consistent with a very slow rate of increase in trophic level (Burns, 2006) (Appendix II).

2.2 Biological monitoring

2.2.1 Methods

During the 2011-2012 monitoring period the biological monitoring of Lake Rotorangi involving the Regional Council included:

- lake phytoplankton communities; and
- a single, brief lake benthic macroinvertebrate fauna survey; an d
- a survey of the dominant macrophytes of the lake

The macrophyte survey was performed in April 2012, with both banks visually surveyed from a moving boat. The dominant species was recorded, with other species observed noted.

Phytoplankton (open-water algae) sub-samples were taken from the chlorophyll-a samples collected from the photic zone at each of the two lake sites in October 2011, February 2012, March 2012, and June 2012. The phytoplankton samples were preserved with Lugol's iodine solution and all samples were later identified under a compound microscope using up to 400 x magnifications by a consultant laboratory.

The benthic macroinvertebrate samples were collected by Ekman dredge from the lakebed at sites L2 and L3 in conjunction with the survey of October 2011. These samples were run through a 0.5mm sieve, before being sorted and identified under a stereoscopic microscope

2.2.2 Results

2.2.2.1 Lake phytoplankton communities

Phytoplankton samples were collected from Lake Rotorangi on 20 October 2011, 21 February, 27 March, and 22 June 2012. These samples were taken from within the photic zone (surface waters) of site L2 and L3. Tables 21 and 22 list the phytoplankton taxa found at each site during the past year. Taxa data from previous years are listed in TRC, 2009, and TRC, 2010.

2.2.2.1.1 Site L2

Site L2 in the central reaches of the lake has generally supported more lake-like algal communities than previously found at site L1 (see TRC, 2009).

Table 21 Phytoplankton found at site L2 in Lake Rotorangi during the 2011-2012 period

Pond	Rotorangi L2	Rotorangi L2	Rotorangi L2	Rotorangi L2
Date	20/10/2011	21/02/2012	27/03/2012	22/06/2012
Lab No.	11240	12140	12192	12302
GREEN ALGAE				
Ultraplankton (too small to ID)		P	P	
Chlorella-like unicells		P		
Closterium/Closteriopsis			P	
Oocystis			P	
Dictyosphaerium	**P**			
Scenedesmus	P	P	P	
CYANOBACTERIA				
Oscillatoria/Planktothrix	P			
DIATOMS				
Nitzschia	P		P	P
Synedra			P	
CRYPTOPHYTES				
Cryptomonas	P	**P**	**P**	**P**
Total taxa number	5	4	7	2

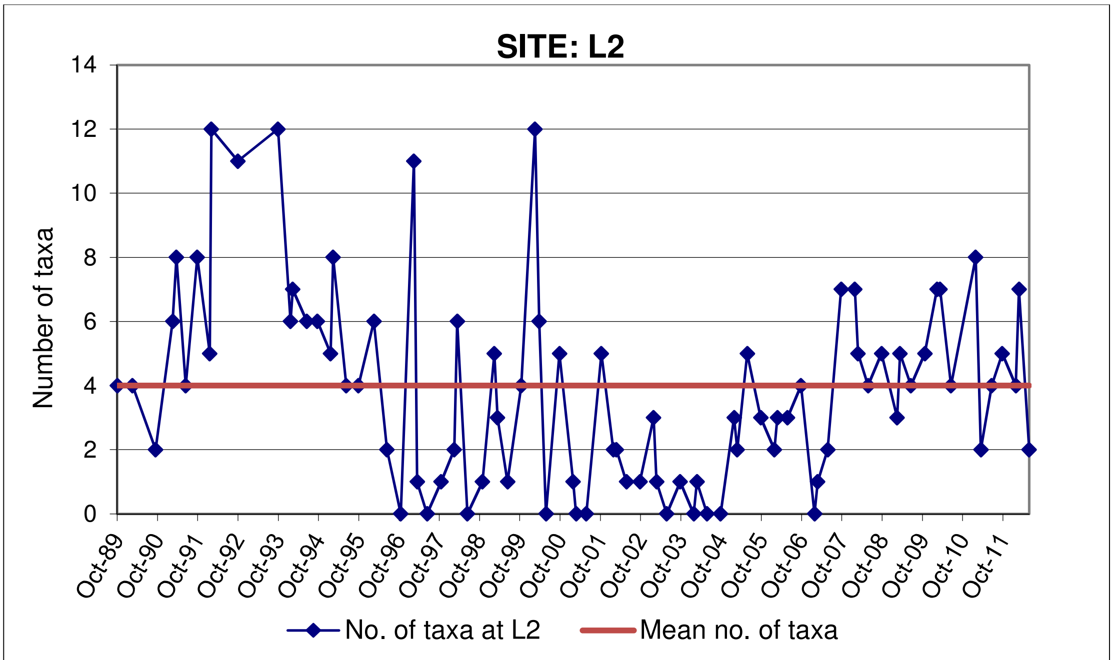


Figure 7 Number of phytoplankton taxa recorded at site L2 in Lake Rotorangi since monitoring began in 1989

Low to moderate numbers of taxa (2 to 7) were present at site L2 during the 2011-2012 monitoring period, with numbers within three taxa of the historical median and average (4 taxa) on all occasions (Figure 7).

The highest taxa richness was found in early autumn, with only two taxa present on the winter occasion. Chlorophyll-a concentration was highest at the time of the February 2012 survey (Table 12), when the phytoplankton community comprised of four taxa, none of which was abundant at this site.

No taxa were found in abundance on any of the four survey occasions but the cryptophyte, *Cryptomonas* was dominant on three occasions (Table 21).

2.2.2.1.2 Site L3

Low to moderate numbers of taxa were also found at L3 during the 2011-2012 monitoring period and similar to historical average (4 taxa) and median (3 taxa) richnesses. This has not been uncommon to date at this site, though it seems to have become a more frequent occurrence, with relatively low numbers and densities of taxa collected during the past eleven years. Four taxa were present in October 2011, six to seven taxa in the late summer-autumn period, and only three taxa in June 2012 (Figure 8). Maximum taxa number in March 2012 was coincident with the highest chlorophyll-a concentration (Table 12).

Table 22 Phytoplankton found at site L3 in Lake Rotorangi in the 2011-2012 period

Pond	Rotorangi L2	Rotorangi L2	Rotorangi L2	Rotorangi L2
Date	20/10/2011	21/02/2012	27/03/2012	22/06/2012
Lab No.	11240	12140	12192	12302
GREEN ALGAE				
Ultraplankton		P	P	
Ankistrodesmus			P	P
Chlorella-like unicells		P		
Actinastrum	P			
Dictyosphaerium	P			
Kirchneriella		P		
Pediastrum			P	
Scenedesmus		P	P	P
DIATOMS				
Asterionella		A		
Synedra			P	
GOLDEN ALGAE				
Dinobryon	P			
CRYPTOPHYTES				
Cryptomonas	**P**	P	P	**P**
Total taxa number	4	6	7	3

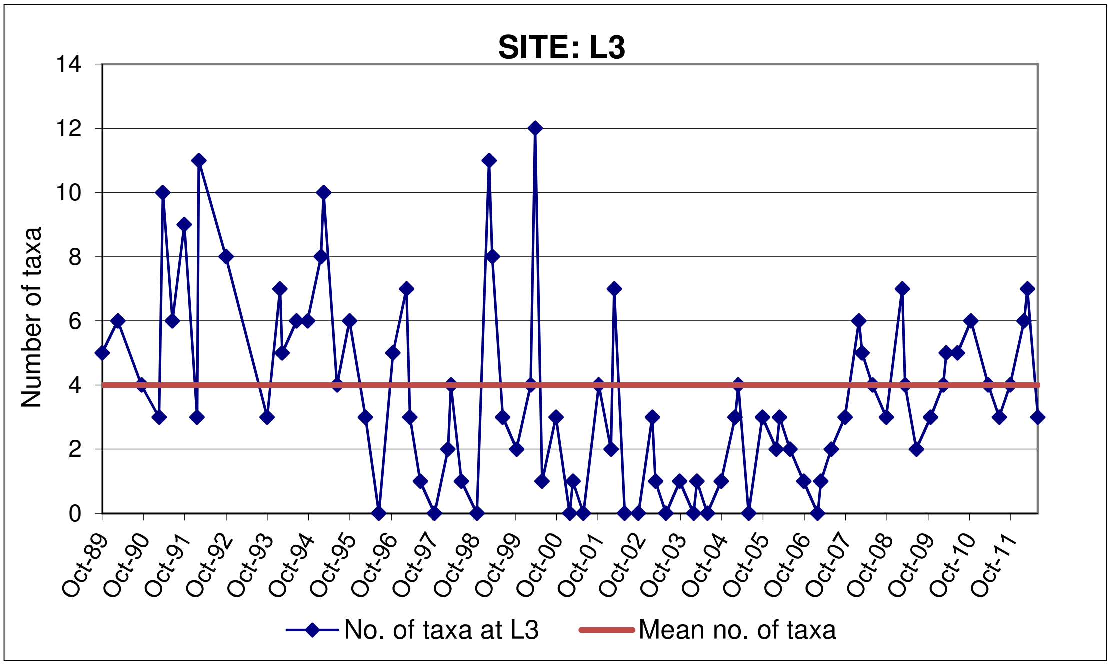


Figure 8 Number of taxa recorded at site L3 in Lake Rotorangi since monitoring began in 1989

Only one individual taxon was present on all survey occasions (cryptophyte, *Cryptomonas*) and only one taxon (diatom, *Asterionella*) was abundant at the time of any of the four surveys.

The cryptophyte, *Cryptomonas* was the dominant taxon (although not abundant) on two occasions (spring and winter) when the populations were low in richness (in terms of taxa number). The diatoms, *Asterionella* and *Synedra* were dominant at the time of the late summer and autumn surveys respectively, although only the former was abundant.

2.2.2.1.3 General comments

Phytoplankton density limiting factors include:

- limited nutrient levels in the lake,
- the settling of algal cells within the dark hypolimnetic waters,
- flood events reducing the clarity of surface waters and flushing surface waters along the length of the lake,
- the limited and variable retention time of water in the lake,
- grazing of phytoplankton by zooplankton (primarily microscopic crustacea), and
- cooler winter temperatures.

The absence of significant blooms of algae to date has indicated that one or more of these limiting factors have prevented algal population increases from continuing for long periods of time. Phytoplankton survey results to date indicate that the open-water algal community composition of Lake Rotorangi is determined by the ability of opportunist taxa to proliferate during the very limited periods of favourable conditions. Phytoplankton provides the food source for the microscopic crustacea in the open water (the major component of zooplankton). Such zooplankton taxa as cladocerans *Daphnia* and *Ceriodaphnia* have been recorded in highly variable densities in Lake Rotorangi in past years. Large numbers of these cladocerans have been recorded in the stomachs of perch (*Perca fluviatilis*) taken from Lake Rotorangi. Some of the algal taxa recorded in the lake phytoplankton are likely to have drifted downstream from the discharge from the Stratford oxidation pond system (where extensive algal populations are a feature of the biological treatment system), and from the mid-reaches of the Patea River. [Note: A major upgrade to the Stratford wastewater treatment plant in 2009 has been designed to reduce the algal population component of the effluent discharge to the river downstream of Stratford (TRC, 2011a)].

In summary, moderate to low taxonomic richnesses were found at all sites throughout the 2011-2012 monitoring year with highest richnesses in autumn, and only one algal taxon was found in abundance. Taxa richness on all survey occasions was similar to, or within three taxa of the running mean number of taxa recorded for each site to date. Phytoplankton results indicate that lake phytoplankton community composition is determined by opportunistic taxa which have the ability to proliferate during favourable conditions and these conditions which may be confined to very limited periods.

2.2.2.2 Benthic macroinvertebrate fauna

A review of the monitoring undertaken by Council staff in late 1991 in conjunction with Dr V M Stout (Department of Zoology, University of Canterbury), indicated that an important additional parameter (benthic macroinvertebrate presence/absence information) should be included as a long term lake status indicator. Sampling from the lake bed (at the deeper sites L2 and L3) was recommended once annually in late winter/spring prior to lake stratification (and the chironomid hatching period).

Generally, the limited information gathered on the macro-benthos of New Zealand lakes indicates that lakes are rather poor in terms of numbers of species, with the main groups found including annelid worms, chironomid midges, ceratopogonid flies and molluscans (Forsyth, 1975 and 1977).

The initial sampling of the lake bed at the deeper sites (L2 and L3) was undertaken in October 1992 with samples collected at similar times over subsequent years using an Ekman dredge. At the time of the October 2011 survey, the faunal samples from the fine greyish-black muddy sediments at sites L2 and L3 were collected from depths of 40 and 51 metres respectively. The macroinvertebrate taxa found to date in the lake benthos are summarised in Table 23.

Table 23 Macroinvertebrate fauna of the Lake Rotorangi benthos at sites L2 and L3

Site	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3
Date	**Oct 1992**		**June 1994**		**Sept 1994**		**Oct 1995**		**Oct 1996**		**Oct 1997**		**Nov 1998**		**Oct 1999**		**Oct 2000**		**October 2001**	
ANNELIDA																				
Oligochaeta	XA	C	C	A	A	XA	XA	XA	C	C	XA	A	XA	C	VA	VA	VA	A	XA	A
Branchiura	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MOLLUSCA																				
Potamopyrgus	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-
Physa	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-
CRUSTACEA																				
Copepoda	R	-	-	-	-	-	-	-	-	-	-	-	R	-	R	-	-	-	-	-
Cladocera	R	-	-	-	-	-	-	-	-	-	-	-	R	-	R	-	R	-	-	-
Ostracoda	C	-	-	-	-	-	-	-	-	-	-	-	R	-	R	-	C	-	-	-
DIPTERA																				
Chironomus zealandicus	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	R	-	R
ACARINA		-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	R	-	-	-
Number of taxa	5	1	1	1	1	1	1	1	1	1	3	1	4	1	5	1	5	2	1	2

Site	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3
Date	**October 2002**		**October 2003**		**October 2004**		**October 2005**		**October 2006**		**October 2007**		**October 2008**		**October 2009**		**October 2010**		**October 2011**	
ANNELIDA																				
Oligochaeta	A	C	C	R	A	A	XA	R	A	A	A	A	A	A	C	A	C	C	A	A
Branchiura	-	-	-	-	-	-	-	-	R	-	-	-	-	R	R	-	-	-	-	-
MOLLUSCA																				
Potamopyrgus	R	R	-	-	-	-	R	-	-	R	-	-	-	-	-	-	-	-	-	-
Physa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CRUSTACEA																				
Copepoda	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cladocera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracoda	C	-	C	-	-	-	R	-	-	R	-	-	-	-	-	-	-	-	-	-
DIPTERA																				
Chironomus zealandicus	-	-	C	-	R	R	R	-	-	-	-	-	-	-	-	-	-	-	R	R
ACARINA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Number of taxa	3	2	4	1	2	2	5	1	1	3	1	1	1	2	2	1	1	1	2	2

[XA = Extremely abundant, A = Abundant, C = Common, R = Rare]

The snails (*Potamopyrgus* and/or *Physa*) found on up to five survey occasions to date amongst the sediments would most likely have fallen to the bed from amongst the extensive marginal weed beds common in the surface waters. Certain crustaceans (cladocerans and copepods), and mites (Acarina), found occasionally as rarities by various surveys, may have been collected from the water column as the dredge passed through the upper layer (where these taxa are normally located).

Otherwise, the very sparse fauna which has continually been found from the lake bed was typical of the fauna of fine sediments from a moderately deep lake. Oligochaete worms (principally Tubificidae) which have been abundant in most surveys, have the ability to survive in poorly oxygenated sediments where they may be present in large numbers. The introduced tubificid, *Branchiura* (characterised by rows of posterior gills [Winterbourn and Mason, 1983])), was found at site L2 for the first time in October 2006 and was present (as a rarity) at site L3 in October 2008 and site L2 in October 2009. Tubificid (oligochaete) worms were found at both sites in October, 2011 and were abundant at site L3 while lumbricid oligochaetes were common at site L2. Ostracod seed shrimps, although not found at either site by the recent survey, may also be common inhabitants of fine sediments. Amongst the chironomid midges, the 'blood-worm' (*Chironomus zealandicus*) is tolerant of very low dissolved oxygen conditions and was present at both sites in low numbers in October, 2011.

The paucity and lack of diversity of the fauna continues to be indicative of low dissolved oxygen levels, consistent with the often lengthy periods of anoxic conditions during lake stratification common to these deeper sites.

2.2.2.3 Aquatic macrophyte survey

A survey of the aquatic macrophytes in Lake Rotorangi was performed on 26 April 2012. None of the tributaries arms of the lake were entered. At regular intervals the macrophyte species seen on the lake edges were recorded on a map of Lake Rotorangi, and the dominant species noted. The dominant taxa were then colour-coded and their distributions are shown in Figure 9, with previous data shown in Figure 10. Surveys are now undertaken as a requirement of consent 0489-2, which requires the survey to be undertaken every three years (date of commencement 2012). The last survey was conducted in February 2008.

Previous macrophyte monitoring, which began in March 1987, found *Egeria densa* dominating the greatest proportion of the lake edges, increasing as time progressed. (Figure 10). Distributions recorded in the previous two surveys (April 2005 and February 2008) indicate that a change in the dominant macrophyte species has occurred since the survey conducted in 2002. Since 1996, *E. densa* had been the most prolific macrophyte in most parts of the lake. However in the 2005 and 2008 surveys, *Lagarosiphon major* was dominant through most reaches, particularly in the mid to lower reaches, with *E. densa* being dominant in smaller patches of the lake, more so at the upper end of the lake. This current survey recorded a distribution more like that recorded in 2002, with *E. densa* being dominant throughout almost the entire length of Lake Rotorangi.

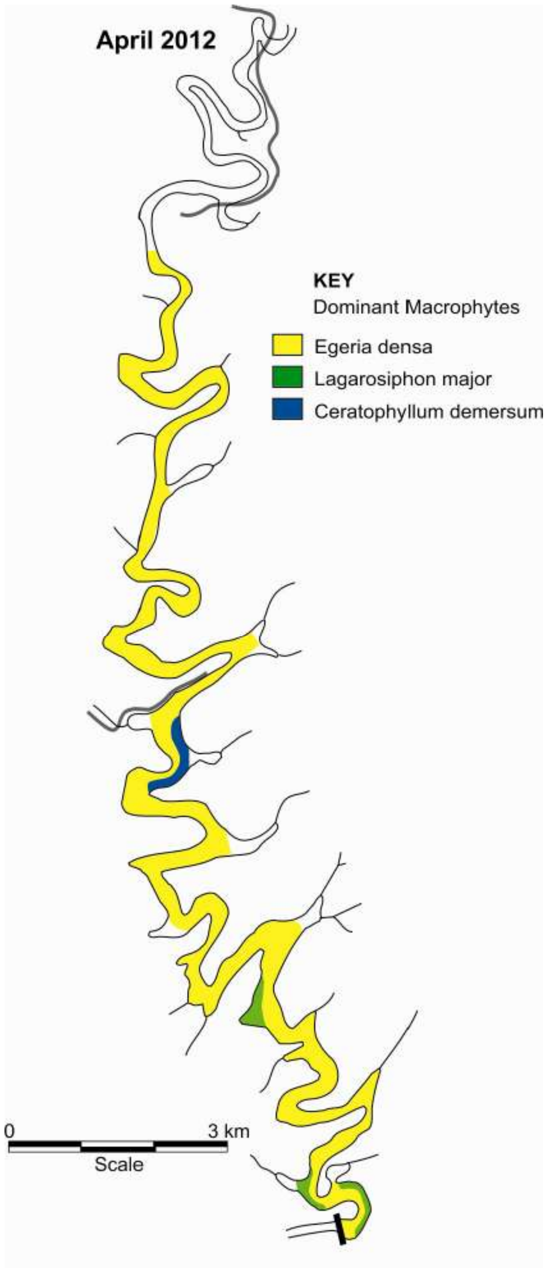


Figure 9 Dominant macrophytes recorded in Lake Rotorangi on 26 April 2012

Two other species were recorded as abundant in areas, being *L. major* and *Ceratophyllum demersum* (Figure 11). This is the first record of *C. demersum* in Lake Rotorangi. *Potamogeton crispus* and *Otellia ovalifolia* were not recorded in the current survey despite being found as dominant in areas during the previous survey. *L. major* was dominant in three areas, closer to the Patea Dam, while *C. demersum* was dominant in one location only, being the true left bank downstream of the Hawera water ski club rooms. *E. densa*, *L. major* and *C. demersum* are introduced aquatic weeds which are listed in the Pest Plant Accord[1], and are thereby considered an 'unwanted organism'. This means that it is illegal to sell, propagate or distribute these plants in New Zealand. *E. densa*, *L. major* are also classified as 'surveillance plants' in the Pest Management Strategy for Taranaki: Plants.

[1] The National Pest Plant Accord (NPPA) is a cooperative agreement between the Nursery and Garden Industry Association, regional councils and government departments with biosecurity responsibilities.

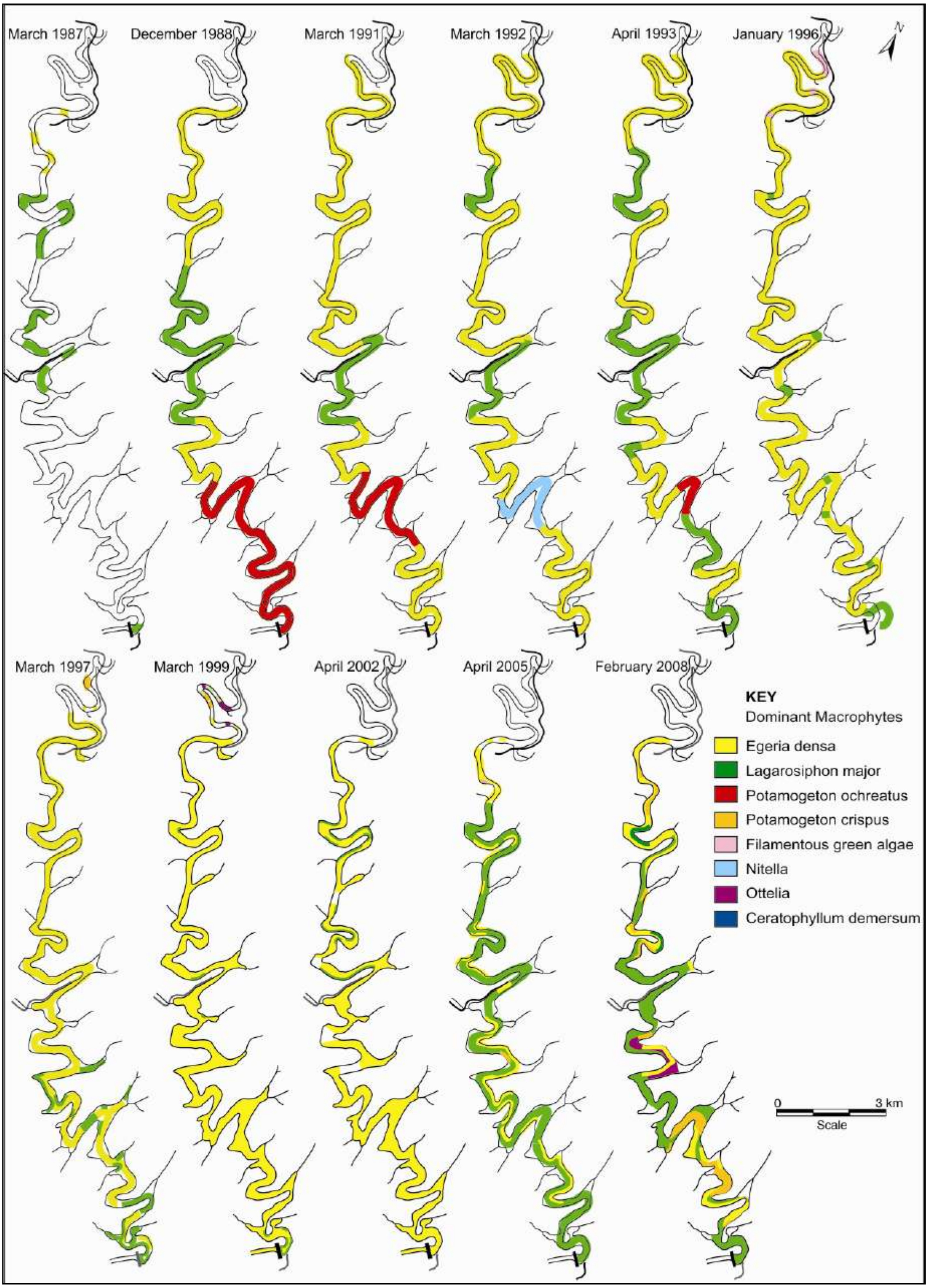


Figure 10 Dominant macrophytes in Lake Rotorangi from March 1987 to February 2008

All three species are distributed throughout the North Island, and *C. demersum* especially can have significant impacts on hydroelectric schemes. However, TrustPower commissioned NIWA[2] to perform an assessment of *C. demersum*, (commonly known as hornwort) and its potential impact on the scheme and ecology of the lake. They concluded that due to a number of factors, there was unlikely to be a significant impact on the hydroelectric scheme, or on the ecology of the lake. *E. densa* tends to thrive in turbid and enriched waters of lakes, whereas *L. major* is more common in clear water lakes of low fertility. It is interesting to note that the dominance of *L. major* is in the middle and lower parts of the lake, which tend to have clearer water; *E. densa* is more dominant in the more riverine upper reaches, and has in the past been often associated with clumps of filamentous green algae, indicating a more enriched environment in these reaches. The upper reaches are also more regularly affected by flooding in the Patea River upstream of the lake, and generally are more turbid than the lower reaches. It is also interesting to note that the dominance of *L. major* reduced in 2012, which was a particularly wet year, and the Patea River was frequently in flood, likely causing a reduction in clarity in the lower lake.

Actual coverage of macrophytes throughout the lake still remains restricted to the edges of the lake and extends further into the middle of the lake only on the inside of the large wide bends where shallow areas permit the spread of these macrophytes. In the areas where the banks drop away quickly macrophytes are generally present in patches rather than continuous thick growths. However this may change with the appearance of *C. demersum*, as this species is known to grow taller and in deeper water than *E. densa* and *L. major*.

A summary of the aquatic macrophyte species found in Lake Rotorangi by the summer – autumn surveys performed between 1986 and 2008 is presented in Table 24.

Figure 11 A dense bed of Ceratophyllum demersum
Photo supplied by NIWA

[2] Lake Rotorangi hornwort assessment. Prepared for TrustPower by NIWA (Rohan Wells) NIWA Client report No. HAM2012-062.

Table 24 Aquatic Macrophytes Recorded From Lake Rotorangi to Date

Species \ Date	Mar-86	Mar-87	Dec-88	Mar-91	Mar-92	Apr-93	Jan-96	Mar-97	Mar-99	Apr-02	Apr-05	Feb -08	Mar-12
Aponogeton distachyus	✓	✓											
Ceratophyllum demersum													✓*
Chara australis													*
Egeria densa	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓*
Elodea canadensis												✓	*
Glossostigma elatinoides													✓*
Lagarosiphon major	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓*
Lilaeopsis ruthiana													*
Nasturtium officinale						✓							
Nitella cristata													*
Nitella hookeri					✓								
Ottelia ovalifolia				✓		✓			✓	✓	✓	✓	
Potamogeton cheesmanii	✓	✓	✓										
Potamogeton crispus	✓	✓		✓		✓		✓		✓	✓	✓	
Potamogeton ochreatus				✓	✓	✓							
Potamogeton pectinus	✓	✓											
Filamentous green algae				✓	✓	✓	✓		✓	✓	✓		✓

✓Recorded by TRC in March 2012 *Recorded by NIWA in April 2012

A total of 16 aquatic macrophytes have been recorded from Lake Rotorangi over the 26 years of the survey period. Two macrophytes (*E. densa* and *L. major*) have been recorded on all survey occasions while two of the remainder have been found on at least four occasions. Including the survey undertaken by NIWA, five species were recorded for the first time in 2012. It is unlikely that four of these species are new additions to the lake, only that they were not previously observed. This is because they were either not widespread, or had growth habits/forms that caused them to be relatively discreet e.g. low growing plants that inhabit deep water. They were therefore very difficult to observe or differentiate during a moving survey, and consequently were only recorded when the boat was stationary (*G. elatinoides*) or by divers (*C. australis, L. ruthiana* & *N. cristata*). It is unlikely that these species will ever become abundant. *C. demersum* on the other hand is considered highly invasive, and is expected to eventually become dominant, out-competing *E. densa* and *L. major*. While this is not expected to cause significant impacts on the ecology of Lake Rotorangi or on the hydroelectric scheme, there is now greater potential for it to spread to nearby lakes, where such impacts could be much more severe e.g. Lake Rotokare. This may be the subject of further investigation by the Taranaki Regional Council.

3. Conclusions

3.1 Discussion of 2011-2012 programme

3.1.1 Water quality

Pre-stratification, two summer stratification, and post-stratification (winter) sampling surveys were performed during the monitoring period at times dictated by requirements for trend detection purposes.

The annual cycle of stratification was recorded in the mid and lower lake during the summer-autumn period with anoxic hypolimnetic water recorded at site L2 and oxygen depleted hypolimnetic water recorded at site L3 (i.e. during February-March 2012). Normal lake overturn was complete at site L2 but only partially complete at site L3 in mid-winter (June 2012). These conditions were similar to those recorded during the majority of the previous monitoring years and are a particular feature of the lower lake site. Complete re-oxygenation of the water column due to further mixing at site L3 might have been anticipated later in winter (as had been the situation recorded in August 2008 and found in July 2012 through readings taken at the log boom as a part of the Patea Hydro Electric Power Scheme - aquatic monitoring plan).

Hypolimnetic oxygen depletion rates and primary productivity measurements (chlorophyll-a) continued to indicate that predicted eutrophic lake conditions have not eventuated. The lake biologically continues to exhibit mesotrophic bordering on eutrophic conditions as confirmed by a NIWA consultant's report (Burns, 1995) commissioned during the 1995-96 period and subsequent follow-up reports (Burns, 1999; Burns et al, 2000 and Burns, 2006) and the most recent TRC trend evaluation for the period 1990 to 2011 (Appendix II). However, relatively high turbidity levels (caused by riverine derived fine silt) from time to time have increased total phosphorus and nitrogen levels and lowered secchi disc values, indicative of a trend toward slightly eutrophic conditions (Burns, 2006). Nutrient supply has been limited principally to those quantities present in the river inflow waters. Despite low dissolved oxygen concentrations and periods of anoxic conditions in the lower waters of the hypolimnion, minimal increases in some nutrient concentrations in these waters (usually due to the increased solubility of nutrients from sediments and decomposing vegetation under reducing conditions), have been recorded, with the main variations relating to relatively small increases in ammonia levels measured during this period with only minor changes in total phosphorus levels.

Variability in levels of turbidity and suspended solids concentrations at the times of the four (2011-2012) surveys were related to the recency of river freshes. Freshes prior to the spring (2011), autumn (2012), and winter (2012) surveys increased turbidity, reducing secchi disc transparency at both sites in the lake, but more so at the mid-lake site L2. As has been noted in the past, lake surface water suspended solids concentrations were not excessive and, at mid and lower lake sites, were due to the finer colloidal material which remained suspended and would be expected to be carried through the lake.

The most recent lake water quality trend analysis, performed by the TRC for the 21 year period 1990-2011 (see Appendix II) has continued to support the findings and conclusions of Burns, 2006. i.e. that the trophic level continues to increase at a very small, insignificant annual rate of change (0.02 ± 0.01 TLI units per year). However, given the tendency for the reservoir water to contain high silt levels, which artificially elevate the trophic index, the trophic category is more appropriately mesotrophic. This is further confirmed by the mesotrophic chlorophyll-a levels. The analysis also notes that there are some insignificant increases in the average concentrations of key variables (secchi disc visibility, chlorophyll-a, total phosphorus, and total nitrogen), with a significant temporal increase in nitrates.

3.1.2 Biology

No phytoplankton blooms were recorded in Lake Rotorangi. The lake has been unable to sustain significant abundances of planktonic algae for long due to the frequency of river freshes. Low to moderate numbers of algal taxa were recorded partly as a result of the frequency of river freshes through the system. Several of the taxa that have been found to date probably originated from the Stratford oxidation pond wastewater treatment system discharge (where extensive algal populations have been a feature of the biological treatment system) and from the mid reaches of the Patea River. Phytoplankton results to date indicate that lake phytoplankton community composition is determined by opportunistic taxa which have the ability to proliferate during favourable conditions which may be confined to very limited periods often due to the frequency of river freshes moving down the lake. Chlorophyll-a concentrations in the lake were low to moderate at all survey times throughout the monitoring period, peaking in late summer at the mid lake site and autumn at the lower lake site.

The summer 2012 macrophyte survey identified the oxygen weed *Egeria densa* as the dominant macrophyte throughout the majority of the lake. Only two other species were recorded as dominant in areas, being *Lagarosiphon major* and *Ceratophyllum demersum* (hornwort). This is the first record of hornwort in Lake Rotorangi. In addition to those species recorded by the Taranaki Regional Council, an additional three new species were recorded by NIWA in April 2012 when commissioned by TrustPower to assess the hornwort community. It is unlikely that these other species will ever become abundant. Hornwort on the other hand is considered highly invasive, and is expected to eventually become dominant, out-competing *E. densa* and *L. major*. While this is not expected to cause significant impacts on the ecology of Lake Rotorangi or on the hydroelectric scheme, there is now greater potential for it to spread to nearby lakes, where such impacts could be much more severe e.g. Lake Rotokare. This may be the subject of further investigation by the Taranaki Regional Council. The next survey is due to be performed in the 2014-2015 period.

Appropriate warning signs about aquatic weeds, positioned at the three principal boat ramps along the lake's length, publicise the problems that could result from the introduction of further nuisance aquatic plants by recreational users, and users' responsibilities for preventing the transportation of aquatic plants between the waterways.

A very sparse macroinvertebrate fauna, confined to oligochaete (mainly tubificids) worms, was again recorded from the fine sediments of the lake bed at the mid and lower lake sites consistent with periodic occurrences of anoxic or oxygen depleted conditions recorded at these two relatively deep sites. Only one other taxon was recorded by the spring survey at sites L2 and L3.

3.2 2010-2011 Report's recommendations

Amongst the recommendations contained in the 2010-2011 Compliance Annual Report based upon the monitoring programme results were:

1. THAT in recognition of the non-performance of the macrophyte survey of the lake, a refund of $1600 is made to the consent holder.

2. THAT an appropriate compliance monitoring programme be formulated in accordance with the requirements of specific conditions attached to the recently renewed consents.

3. THAT the Lake Rotorangi physicochemical and biological water quality monitoring programme continue as a component of both 2 (above) and the TRC State of the Environment Monitoring programmes.

Recommendations 1 and 2 were implemented. Recommendation 3 was implemented in part, with the development of a State of the Environment monitoring programme to include the physicochemical and biological water quality monitoring. Once every three years this is undertaken at TrustPower's expense, as required by consent 0489, and this is included in the Patea Hydro Electric Power Scheme - aquatic monitoring plan.

3.3 Alterations to monitoring programme for 2012-2013

In the case of the State of the Environment Monitoring Programme for Lake Rotorangi, it is considered that the current monitoring is appropriate, with every third year of the programme to be performed in conjunction with the Patea Hydro Electric Power Scheme - aquatic monitoring plan, which is next to be conducted in the 2014-2015 period.

A recommendation to this effect is attached to this report.

4. Recommendation

The following recommendation is based on the results of the 2011-2012 water quality and biological monitoring programme and the contractual requirements of the recently renewed consents.

1. THAT the Lake Rotorangi physicochemical and biological water quality monitoring programme continue on an annual basis as a component of the TRC State of the Environment Monitoring programme, with every third year of the programme also undertaken in conjunction with the Patea Hydro Electric Power Scheme - aquatic monitoring plan.

Glossary of common terms and abbreviations

The following abbreviations and terms are used within this report:

anoxia	absence of dissolved oxygen
aquatic macrophyte	water plants
benthic	bottom living
black/secchi disc	measurement of visual clarity (metres) through the water (horizontally/vertically)
biomonitoring	assessing the health of the environment using aquatic organisms
chlorophyll-a	productivity using measurement of phytoplankton pigment (mg/m^3)
cumec	volumetric measure of flow (cubic metre per second)
condy	Conductivity, an indication of the level of dissolved salts in a sample, usually measured at 20°C and expressed in mS/m
DO	dissolved oxygen measured as g/m^3 (or saturation (%))
DRP	dissolved reactive phosphorus
E.coli	*Escherichia coli*, an indicator of the possible presence of faecal material and pathological micro-organisms. Expressed as the number of organisms per 100ml
epilimnion	lake zone above the thermocline (mixed surface layer)
Faecal coliforms	an indicator of the possible presence of faecal material and pathological micro-organisms. Expressed as the number of organisms per 100ml
fresh	elevated flow in a stream, such as after heavy rainfall
g/m^3	grammes per cubic metre, and equivalent to milligrammes per litre (mg/L). In water, this is also equivalent to parts per million (ppm), but the same does not apply to gaseous mixtures
hypolimnion	zone below the thermocline in a stratified lake
l/s	litres per second
mesotrophic	intermediate condition of nutrient enrichment between oligotrophic and eutrophic in lakes
mS/m	millisiemens per metre
NH_4	ammonium, normally expressed in terms of the mass of nitrogen (N)
NO_3	nitrate, normally expressed in terms of the mass of nitrogen (N)
NTU	Nephelometric Turbidity Unit, a measure of the turbidity of water
overturn	remixing of a lake after stratification
pH	a numerical system for measuring acidity in solutions, with 7 as neutral. Numbers lower than 7 are increasingly acidic and higher than 7 are increasingly alkaline. The scale is logarithmic i.e. a change of 1 represents a ten-fold change in strength. For example, a pH of 4 is ten times more acidic than a pH of 5
photic zone	upper section of lake penetrated by light
physicochemical	measurement of both physical properties(e.g. temperature, clarity, density) and chemical determinants (e.g. metals and nutrients) to characterise the state of an environment
plankton	plants and animals freely moving in open water
resource consent	refer Section 87 of the RMA. Resource consents include land use consents (refer Sections 9 and 13 of the RMA), coastal permits (Sections 12, 14 and 15), water permits (Section 14) and discharge permits (Section 15)
RMA	Resource Management Act 1991 and subsequent amendments
SS	suspended solids
stratification	formation of thermal layers in lakes

temp	temperature, measured in °C (degrees Celsius)
thermocline	zone of most rapid temperature change in stratified lakes
trophic level	amount of nutrient enrichment of a lake
turb	turbidity, expressed in NTU
UI	Unauthorised Incident
UIR	Unauthorised Incident Register – contains a list of events recorded by the Council on the basis that they may have the potential or actual environmental consequences that may represent a breach of a consent or provision in a Regional Plan
VHOD	Volumetric hypolimnetic oxygen depletion. The note of dissolved oxygen decrease in the lower layer of the lake under stratified conditions. A measure of lake productivity
water column	water overlying the lake bed

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Appendix I

Flow data for the Patea River at Skinner Road, the Mangaehu River at Raupuha Road bridge, and the synthesised inflow into Lake Rotorangi for the period 1 July 2011 to 30 June 2012

Source is R:\PROCESSING-FILE\WATER TAKES & DISCHARGES.hts
Synthetic Inflow (m3/sec) at Patea Dam
From 1-Jul-2011 00:00:00 to 30-Jun-2012 23:45:00
24 hour periods beginning at midnight each day.

Daily means Years 2011-2012 Synthetic Inflow(m3/sec) at Patea Dam

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
1	21.568	12.961	11.258	8.650	17.586	8.815	202.880	7.458	25.894	11.885	9.950	15.087	
2	19.281	13.217	10.149	16.917	106.697	7.839	124.841	7.859	21.286	11.107	7.641	13.560	
3	17.307	14.354	9.456	67.785	89.659	7.524	46.072	9.472	86.532	10.365	6.754	12.789	
4	16.176	13.346	8.975	160.370	47.436	8.013	26.709	9.813	97.329	9.571	6.270	12.488	
5	15.597	12.510	8.516	58.155	31.213	16.624	19.871	11.424	35.548	8.782	6.063	16.499	
6	22.765	12.024	8.266	32.982	23.991	18.015	16.060	11.716	23.448	8.201	5.926	49.799	
7	37.071	12.733	8.058	25.699	21.843	23.634	13.514	8.627	18.720	7.828	5.880	45.893	
8	81.437	17.953	7.972	20.183	18.632	19.114	20.759	7.173	15.394	7.561	5.929	26.423	
9	59.911	13.557	7.980	17.504	16.763	11.814	34.466	6.541	13.292	7.406	6.749	20.524	
10	93.707	11.876	10.200	15.511	18.767	9.095	21.987	6.233	11.980	7.264	8.175	17.841	
11	94.644	15.960	11.198	20.114	17.104	8.263	17.718	6.545	11.725	7.636	16.740	15.543	
12	160.224	33.964	17.281	32.875	13.909	8.069	15.107	6.793	25.405	20.014	13.169	13.900	
13	98.629	49.758	23.347	80.481	13.415	13.167	40.344	6.055	18.025	15.367	9.669	12.154	
14	82.796	30.350	23.048	52.291	12.430	16.080	32.576	15.900	12.298	9.897	74.207	11.315	
15	66.662	42.355	19.911	30.848	11.281	54.094	23.953	36.453	10.660	8.124	153.752	11.057	
16	43.989	38.634	21.088	28.143	10.672	89.376	18.041	15.213	9.823	7.496	71.434	12.609	
17	32.052	30.224	18.016	23.962	10.516	92.003	14.227	12.372	9.133	7.204	44.491	12.849	
18	25.656	37.284	17.193	44.025	9.788	60.076	11.828	9.006	8.654	6.930	31.371	11.466	
19	21.851	33.336	20.837	49.839	9.068	27.116	10.439	7.456	8.391	6.506	23.936	40.148	
20	19.226	27.224	30.734	45.863	8.308	18.333	9.597	6.694	10.838	6.247	19.450	49.791	
21	17.411	21.932	22.900	28.398	8.307	13.942	8.870	6.409	11.916	6.197	16.714	60.398	
22	18.098	19.225	17.167	22.772	10.520	11.543	8.061	16.985	57.514	6.219	14.596	38.013	
23	16.730	17.290	14.682	20.693	9.443	9.763	8.214	69.703	84.926	6.050	13.167	26.727	
24	15.764	15.822	13.194	17.846	23.364	8.449	7.169	44.757	46.788	5.941	12.176	44.076	
25	17.679	14.725	14.889	15.714	25.124	7.577	6.303	20.220	45.594	5.802	11.566	39.149	
26	15.276	13.923	15.035	14.307	11.697	6.962	7.419	14.923	32.170	5.853	10.987	42.027	
27	15.200	13.445	11.874	19.637	9.010	6.640	9.124	12.068	22.841	8.157	26.220	58.567	
28	27.144	12.507	10.593	38.194	8.180	6.212	11.403	10.897	18.983	13.050	57.632	50.293	
29	19.553	11.678	9.888	24.433	15.024	5.862	8.984	12.747	16.261	10.886	31.078	34.604	
30	16.132	11.604	9.283	27.313	12.581	31.415	7.913		14.151	9.349	20.718	?	
31	14.690	12.287		21.359		171.762	7.460		12.873		17.514		
Min	14.690	11.604	7.972	8.650	8.180	5.862	6.303	6.055	8.391	5.802	5.880	11.057	5.802
Mean	39.491	20.583	14.433	34.931	21.411	25.716	26.191	14.397	27.045	8.763	24.514	28.124	23.901
Max	160.224	49.758	30.734	160.370	106.697	171.762	202.880	69.703	97.329	20.014	153.752	60.398	202.880

Source is R:\ARCHIVES\HYDRO-ARCHIVES.HTS
Flow (m3/sec) at Mangaehu at Bridge
From 1-Jul-2011 00:00:00 to 30-Jun-2012 24:00:00
24 hour periods beginning at midnight each day.

Daily means Years 2011-2012 Flow(m3/sec) at Mangaehu at Bridge

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
1	11.910	8.305	6.285	4.755	9.197	4.418	129.230	4.034	15.411	5.761	5.849	6.906	
2	10.702	7.936	5.597	4.795	56.667	3.761	80.370	4.332	12.839	5.433	4.315	6.124	
3	9.620	7.808	5.225	13.896	55.685	3.528	27.134	5.232	46.948	5.098	3.745	5.832	
4	8.971	7.273	4.956	85.338	27.518	3.785	14.656	5.686	60.415	4.744	3.448	5.783	
5	8.664	6.829	4.707	31.608	17.138	5.196	10.744	6.939	19.672	4.363	3.321	6.005	
6	13.032	6.606	4.577	16.109	12.789	8.226	8.715	7.168	12.265	4.081	3.249	22.369	
7	21.432	6.992	4.484	12.563	11.804	12.752	7.503	5.063	9.636	3.908	3.228	26.285	
8	46.551	10.669	4.465	9.754	9.838	10.158	10.516	4.102	7.834	3.807	3.267	13.672	
9	34.996	7.836	4.500	8.498	8.783	5.487	18.021	3.696	6.673	3.784	3.424	10.352	
10	56.218	6.763	5.845	7.513	10.397	3.858	10.561	3.532	5.979	3.739	4.206	9.031	
11	57.953	9.165	6.181	8.159	9.401	3.321	8.819	3.755	5.873	3.954	7.794	7.830	
12	103.800	19.873	9.685	15.700	7.312	3.080	7.666	3.946	11.906	10.820	7.319	7.039	
13	58.794	32.298	14.235	45.901	7.141	5.332	15.380	3.460	9.814	8.616	4.822	6.090	
14	48.232	18.696	13.667	30.291	6.601	5.435	17.038	8.929	6.286	5.410	38.553	5.656	
15	39.066	26.604	11.957	16.468	5.894	11.477	12.773	24.405	5.312	4.368	99.050	5.627	
16	25.143	24.362	12.667	15.325	5.509	51.801	9.780	9.735	4.920	4.001	41.514	6.649	
17	17.992	17.345	10.545	12.817	5.540	37.149	7.804	7.815	4.576	3.853	22.333	7.158	
18	14.328	18.147	9.663	19.097	5.123	31.951	6.554	5.479	4.343	3.724	15.737	5.795	
19	12.317	16.502	12.368	25.813	4.691	12.544	5.998	4.472	4.205	3.494	11.650	15.335	
20	10.984	13.395	18.112	26.123	4.246	8.050	5.742	3.968	4.694	3.345	9.311	27.409	
21	10.108	10.919	13.545	15.005	4.197	5.996	5.594	3.747	5.346	3.329	7.946	31.962	
22	10.386	9.713	9.750	11.807	5.833	4.993	5.228	5.399	26.255	3.356	6.898	20.450	
23	10.063	8.816	8.170	10.873	5.112	4.230	5.697	31.072	40.779	3.275	6.188	13.728	
24	9.020	8.146	7.222	9.259	14.651	3.677	5.059	26.341	25.186	3.225	5.697	22.411	
25	9.210	7.668	8.597	8.050	15.682	3.347	4.450	10.575	21.028	3.141	5.439	22.773	
26	9.071	7.345	8.815	7.329	6.543	3.093	4.301	7.586	15.809	3.184	5.206	24.621	
27	8.621	7.203	6.705	10.869	4.743	3.041	4.748	5.970	10.724	3.941	5.765	35.772	
28	16.774	6.708	5.888	21.035	4.107	2.908	6.556	5.410	8.911	7.623	27.635	29.913	
29	12.061	6.266	5.480	13.113	8.518	2.758	4.931	6.863	7.723	6.380	15.752	19.535	
30	9.899	6.275	5.127	15.003	6.925	6.318	4.270		6.741	5.256	9.675	14.097	
31	9.312	6.854		11.626		91.610	3.986		6.186		8.044		
Min	8.621	6.266	4.465	4.755	4.107	2.758	3.986	3.460	4.205	3.141	3.228	5.627	2.758
Mean	23.394	11.591	8.301	17.564	11.919	11.719	15.156	7.887	14.009	4.634	12.915	14.740	12.878
Max	103.800	32.298	18.112	85.338	56.667	91.610	129.230	31.072	60.415	10.820	99.050	35.772	129.230

Source is R:\ARCHIVES\HYDRO-ARCHIVES.HTS
Flow (m3/sec) at Patea at Skinner Rd
From 1-Jul-2011 00:00:00 to 30-Jun-2012 24:00:00
24 hour periods beginning at midnight each day.

Daily means Years 2011-2012 Flow(m3/sec) at Patea at Skinner Rd

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
1	4.406	3.607	2.212	1.804	4.681	1.319	23.103	1.646	4.081	3.449	1.576	4.322	
2	3.872	3.343	2.087	10.224	24.958	1.257	13.840	1.657	2.987	3.163	1.437	3.938	
3	3.479	3.092	1.938	48.715	9.386	1.204	9.707	1.947	20.787	2.919	1.366	3.613	
4	3.292	2.859	1.842	32.865	7.353	1.221	7.636	1.691	10.157	2.644	1.308	3.392	
5	3.157	2.668	1.745	11.872	5.994	6.954	6.268	1.571	6.984	2.415	1.280	8.451	
6	4.481	2.513	1.685	9.305	5.128	4.031	5.336	1.497	5.602	2.253	1.252	15.269	
7	6.529	2.742	1.616	7.227	4.465	2.557	4.565	1.372	4.687	2.136	1.236	8.102	
8	11.798	2.708	1.561	5.860	4.034	1.903	8.739	1.290	3.972	2.021	1.234	6.550	
9	10.611	2.315	1.542	5.044	3.710	1.620	10.720	1.237	3.564	1.913	1.821	5.551	
10	13.839	2.173	1.855	4.548	3.484	1.467	9.013	1.169	3.260	1.844	2.095	4.843	
11	14.270	3.013	2.612	8.048	3.183	1.413	7.047	1.174	3.347	2.186	5.301	4.331	
12	14.033	5.846	3.213	11.073	2.973	1.576	6.255	1.150	7.946	4.362	2.444	3.865	
13	15.881	3.996	3.158	14.139	2.752	2.709	20.928	1.095	3.759	2.847	2.600	3.527	
14	15.145	3.791	3.566	8.458	2.542	5.114	11.258	3.455	3.144	2.066	20.329	3.360	
15	11.877	4.756	2.811	6.900	2.399	32.153	8.494	1.847	2.906	1.813	12.146	3.175	
16	9.180	3.974	3.088	5.954	2.336	11.405	6.739	1.357	2.653	1.716	11.613	3.405	
17	7.516	5.593	2.886	5.817	2.157	37.260	5.632	1.259	2.465	1.639	11.111	2.950	
18	6.336	10.926	3.430	15.378	2.034	13.360	4.908	1.170	2.336	1.550	7.994	4.489	
19	5.462	9.190	3.218	12.565	1.915	8.764	4.303	1.058	2.276	1.463	6.506	17.450	
20	4.842	7.538	4.952	7.966	1.817	6.664	3.870	1.005	3.977	1.419	5.451	11.682	
21	4.427	5.956	3.454	6.428	1.900	5.373	3.432	1.055	4.972	1.396	4.711	14.877	
22	4.824	5.065	3.157	5.479	1.742	4.523	3.133	10.016	18.882	1.380	4.121	9.249	
23	4.016	4.461	2.919	4.788	1.681	3.920	2.864	23.087	25.151	1.329	3.735	7.621	
24	4.712	3.986	2.797	4.244	2.238	3.467	2.599	6.540	10.229	1.295	3.452	12.854	
25	6.087	3.605	2.620	3.848	1.822	3.121	2.440	4.716	14.672	1.275	3.214	7.808	
26	4.205	3.291	2.404	3.512	1.572	2.912	2.281	3.773	8.879	1.273	2.987	8.519	
27	5.116	3.041	2.236	4.000	1.452	2.728	2.266	3.259	7.011	2.532	18.708	9.277	
28	6.036	2.814	2.124	7.757	1.505	2.528	2.015	2.942	5.841	2.123	14.274	9.033	
29	4.806	2.630	2.004	5.081	1.741	2.459	1.867	2.766	4.898	1.726	7.201	7.873	
30	4.436	2.567	1.902	5.535	1.397	22.807	1.749		4.249	1.825	5.849	6.521	
31	3.902	2.436		4.264		45.344	1.707		3.805		5.050		
Min	3.157	2.173	1.542	1.804	1.397	1.204	1.707	1.005	2.276	1.273	1.234	2.950	1.005
Mean	7.180	4.080	2.555	9.313	3.812	7.843	6.604	3.028	6.757	2.066	5.594	7.196	5.533
Max	15.881	10.926	4.952	48.715	24.958	45.344	23.103	23.087	25.151	4.362	20.329	17.450	48.715

Appendix II

TRC Lake Rotorangi water quality trend analysis 1990-2011

Memorandum

To	CR Fowles, Scientific Officer
From	Alex Connolly, Scientific Officer
Document	1083598
Date	September 2012

Lake Rotorangi trend analysis January 1990 to December 2011

Introduction

A trend analysis of Lake Rotorangi monitoring data from 1990 to 2011 has been undertaken to update analysis conducted by Burns (2006) for data from 1990-2006. This memo provides very little interpretation of the trend analysis, but reproduces analyses provided in the previous report by Burns (2006).

Methods of analysis

The methods of data analysis used are those recommended in the "Protocol for Monitoring New Zealand Lakes (Burns et. al., 2000) that has been published by the Ministry for the Environment. The calculations and plots have been done using the computer programme, LakeWatch. Refer to Burns (2006) for a more detailed explanation of the methods.

Results and discussion

Table 1 summarises the results of the trend analysis of parameters for each individual site (L2 and L3) as well as both sites combined. Table in Appendix 1 provides the *p* and R values for these trends.

This trend analysis indicates that while many of the parameters are not significantly changing over time, there is significant deterioration in nitrate nitrogen when both sites are considered together. The Percent Annual Change (PAC) was calculated for those trends which were significant (PAC=slope/period average*100) and indicated that when data from sites L2 and L3 are combined, nitrate nitrogen is increasing by 2.5% per year (or 8.12 $mgN/m^3/year$) and electrical conductivity (as µS/cm at 20^oC) is increasing by 0.3% per year (0.06 µS/cm/year). Figure 1, Figure 2 and Figure 3 present the significant trends graphically for the combined sites data. Trends are also presented graphically for all parameters for individual sites in Appendices 2 and 3.

Interestingly, recent trend analysis of three sites in the upstream catchment of the Patea River (Patea River at Barclay Road and Skinner Road, and Mangaehu River at Raupuha Road) indicated a significant deterioration in nitrate nitrogen at the Skinner Road site (mid catchment) of a similar magnitude (1.6%/year), there was also significant deteriorations in dissolved reactive phosphorus at Barclay Road near the National Park (2%/year) and in the Mangaehu River (2%/year), unusually there is no significant deterioration of dissolved reactive phosphorus evident in this lake trend analysis update (Connolly, 2012).

Table 1 Trends in water quality parameters in Lake Rotorangi for monitoring conducted from 1990 to 2011

Parameter	L2	L3	L2 & L3
Chlorophyll *a*	😐	😐	☹ (orange)
DO	☹ (red)	😐	😐
EC	☹ (orange)	😐	☹ (orange)
Secchi Depth	😐	😐	😐
TSS	😐	😐	😐
Temperature	😐	😐	😐
DRP	😐	😐	😐
NH_4	😐	😐	😐
NO_3	☹ (red)	☹ (red)	☹ (red)
TN	😐	😐	😐
TP	😐	😐	😐
HVOD	😐	😐	😐
TLI	😐	😐	😐

Key:

☺ (dark green) statistically very significant **improvement** P<0.01 (1%)

☺ (light green) statistically significant **improvement** P<0.05 (1%)

😐 (grey) **no statistically significant change**

☹ (orange) statistically significant **deterioration** P<0.05 (5%)

☹ (red) statistically very significant **deterioration** P<0.01 (less than 1% probability that the trend is due to natural variability and doesn't represent an actual change)

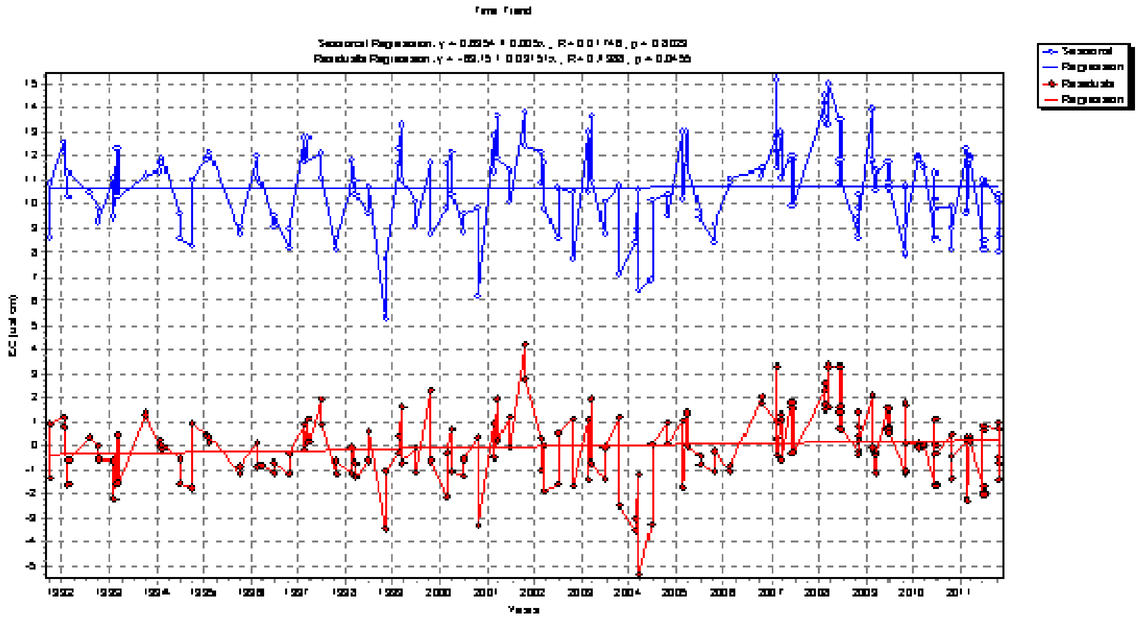


Figure 1 Electrical conductivity (EC) trend line for sites L2 and L3 combined

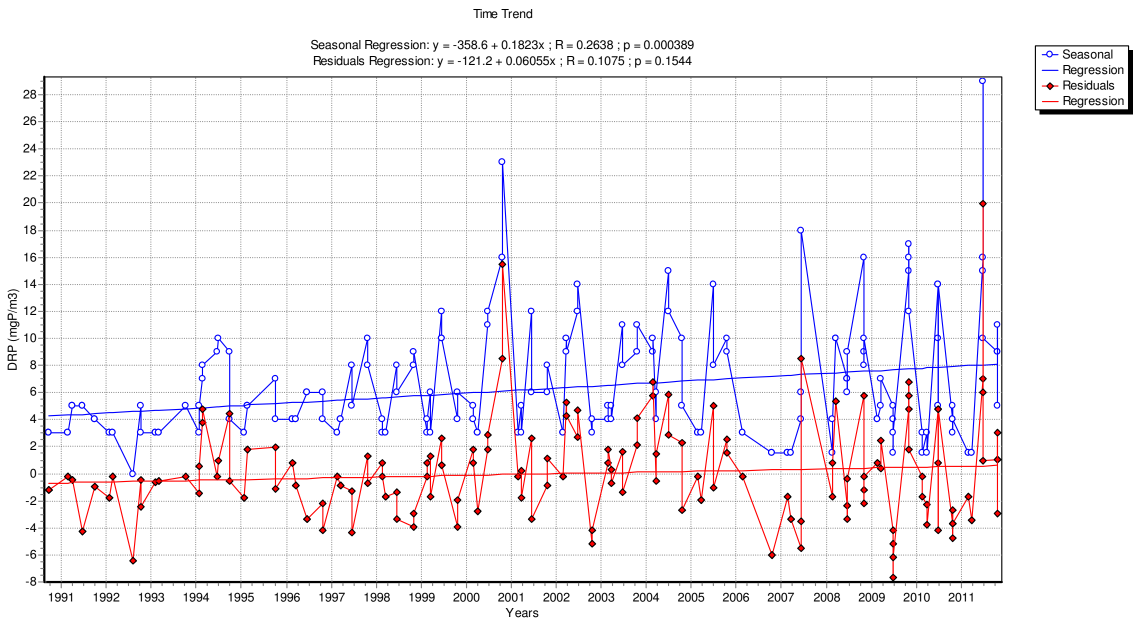


Figure 2 Dissolved Reactive Phosphorus DRP trend line for sites L2 and L3 combined

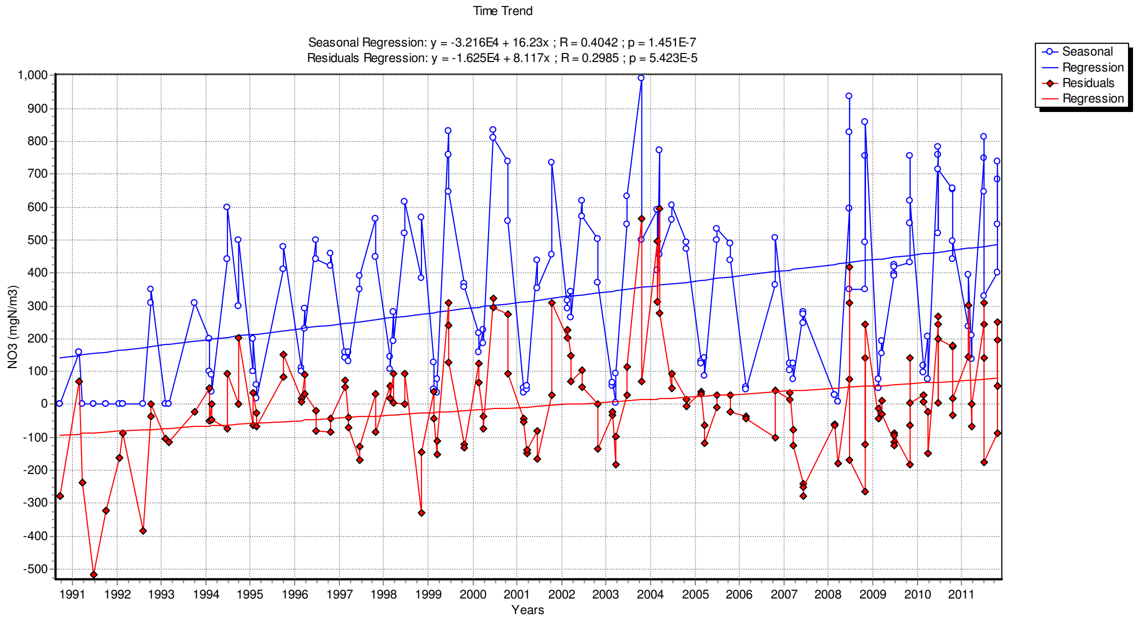


Figure 3 Nitrate nitrogen (NO3) trend line for sites L2 and L3 combined

The Trophic Level Index (TLI) values are shown in Table 2 for sites L2 and L3 combined. The TLI is calculated by converting the annual average values of chlorophyll a, secchi disc, total phosphorus and total nitrogen into the variable trophic level values of TLc, TLs, TLp and TLn respectively (collectively these are labelled as TLx values) and the averages of these four values gives the annual TLI values. The average of the annual values gives the trophic level of the lake. In a balanced lake, these values are of similar magnitude.

The average TLI for the 1990-2011 period is 4.15 (±0.07) (Table 2). This indicates that the lake is eutrophic as per the following table (reproduced from Burns (2006)). However, when the individual key variables are compared with the trophic levels, chlorophyll a and secchi depth indicate that the lake is in a mesotrophic state, and the nutrients indicate a eutrophic state (see highlighted areas in table below). When the sites are looked at individually the TLI of L2 continues to be slightly eutrophic however L3 has crept into the mesotrophic boundary within this year's analysis. Therefore site L2 continues to be more eutrophic at a TLI of 4.24 (possibly as a result of this site's proximity to the upper catchment) due to the secchi depth moving from mesotrophic to eutrophic at this site, and higher nutrient concentrations (refer to Appendices 2 and 3). The L3 TLI (3.84) indicated mesotrophic conditions in the 2011 year of monitoring.

The TLI is not changing significantly over time (i.e., the trend is not significant at $p<0.05$). However in Burns' (2006) report, he notes that while there are no 'significant' trends in the trophic level or the average concentrations of the key variables (Chl a, Secchi, TP, TN), there are some insignificant increases in these variables; and coupled with significant trend in NO_3, suggests that the trophic level is increasing, albeit at a very small rate of change (0.02 ±0.01 units per year), which he notes is not a cause for major concern. The current trend analysis continues to support this conclusion.

Hypolimnetic Volumetric Oxygen Depletion (HVOD) has been calculated for sites L2 and L3 using the Lakewatch programme. The hypolimnion depths have been fitted to dissolved oxygen profiles for each year of analysis in the summer monitoring months of February and

March; these values are based on recommendations by Chris Fowles from past assessments of the stratification depth profiles. The HVOD p values indicate that there has been no significant change over the 1990-2011 period. Furthermore the HVOD analysis has been discussed at a national level and it has not been recommended for annual use in future national monitoring and reporting (NIWA, 2011). TRC currently produce a yearly HVOD summary however on the basis of work currently being undertaken by NIWA and MfE it may not be applicable for future analysis of Lake Rotorangi. There have also been discrepancies over HVOD data currently stored in Lakewatch due to some difficulties with using the software in the 2011 analysis; interpretation of this data should be viewed with caution. TRC will continue to be updated with national monitoring protocols and follow any guidance and instruction where necessary when monitoring and reporting on Lake Rotorangi.

Table 2 Values of key variables that define the boundaries of different Trophic Levels (highlighted areas relate to the status of Lake Rotorangi using 1990-2011 data)

Lake Type	Trophic Level	Chl a (mg m^{-3})	Secchi Depth (m)	TP (mg P m^{-3})	TN (mg N m^{-3})
Ultra-microtrophic	0.0 - 1.0	0.13 - 0.33	33 - 25	0.84 - 1.8	16 - 34
Microtrophic	1.0 to 2.0	0.33 - 0.82	25 -15	1.8 - 4.1	34 73
Oligotrophic	2.0 to 3.0	0.82 - 2.0	15 - 7.0	4.1 - 9.0	73 -157
Mesotrophic	3.0 to 4.0	2.0 - 5.0	7.0 - 2.8	9.0 - 20	157 - 337
Eutrophic	4.0 to 5.0	5.0 - 12	2.8 - 1.1	20 - 43	337 - 725
Supertrophic	5.0 to 6.0	12 - 31.0	1.1 - 0.4	43 - 96	725 -1558
Hypertrophic	6.0 to 7.0	>31	<0.4	>96	>1558

References

Burns N.M., 2006: Water quality trends in Lake Rotorangi, 1990-2006. Report prepared for NIWA, October 2006.

Burns N.M., Bowman E and Bryers G., 2000: Protocol for monitoring the trophic levels of New Zealand Lakes and Reservoirs. New Zealand Ministry for the Environment, Wellington, NZ. 138p.

Connolly A, 2012: Trends in regional physicochemical water quality data for Taranaki: a comparison of 1995-2011 (16 year data set). TRC Internal Memo.

NIWA, 2011: Investigation of single indicators for water quality assessment and reporting-Prepared for the Ministry for the Environment. 108-113p.

Percent annual change and Burns Trophic Index values and trends for L2 and L3 data combined for the 1990-2011 period

LAKE ROTORANGI

L2 & L3 1990-2011 (1 Jan 1990 - 31 Dec 2011)

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	0.06	(-0.01)	(-0.11)	(2.03)	1.11			
Average Over Period	2.96	(2.83)	(24.75)	(629.15)	-12.36			
Percent Annual Change (%/Year)	**2.03**	**0.00**	**0.00**	**0.00**	**-8.98**	**-1.39**	**1.94**	**0.51**

Burns 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
Jan 1990 - Dec 1990	3.93	1.50	16.33	960.00	3.73	5.06	3.76	5.37	4.48	0.43			
Jan 1991 - Dec 1991	2.79	2.61	15.88	661.25	3.35	4.40	3.72	4.88	4.09	0.34			
Jan 1992 - Dec 1992	2.96	2.33	14.00	300.00	3.42	4.54	3.56	3.85	3.84	0.25			
Jan 1993 - Dec 1993	2.20	4.47	15.80	140.00	3.09	3.74	3.72	2.85	3.35	0.22			
Jan 1994 - Dec 1994	1.70	2.58	28.75	595.00	2.81	4.41	4.48	4.74	4.11	0.44			
Jan 1995 - Dec 1995	2.73	2.82	30.50	388.33	3.33	4.30	4.55	4.18	4.09	0.27			
Jan 1996 - Dec 1996	2.70	3.04	22.25	567.50	3.32	4.22	4.15	4.68	4.09	0.28			
Jan 1997 - Dec 1997	1.69	2.98	16.00	561.25	2.80	4.24	3.73	4.66	3.86	0.40			
Jan 1998 - Dec 1998	2.41	2.47	50.25	677.50	3.19	4.47	5.19	4.91	4.44	0.44			
Jan 1999 - Dec 1999	2.58	3.77	22.78	601.11	3.26	3.95	4.18	4.75	4.04	0.31			
Jan 2000 - Dec 2000	3.04	2.71	23.50	778.75	3.45	4.35	4.22	5.09	4.28	0.34			
Jan 2001 - Dec 2001	2.40	4.02	12.75	762.50	3.19	3.87	3.45	5.07	3.89	0.42			
Jan 2002 - Dec 2002	3.93	2.19	28.00	836.25	3.73	4.61	4.44	5.19	4.49	0.30			
Jan 2003 - Dec 2003	1.54	3.23	29.63	615.00	2.69	4.14	4.52	4.78	4.03	0.47			
Jan 2004 - Dec 2004	4.20	0.92	51.63	885.00	3.80	5.63	5.22	5.26	4.98	0.40			
Jan 2005 - Dec 2005	2.75	2.97	21.13	557.50	3.34	4.24	4.09	4.66	4.08	0.28			
Jan 2006 - Dec 2006	1.50	3.09	15.75	490.00	2.67	4.19	3.71	4.49	3.77	0.40			
Jan 2007 - Dec 2007	5.01	2.58	25.30	675.00	4.00	4.42	4.32	4.91	4.41	0.19			
Jan 2008 - Dec 2008	2.29	3.43	18.00	645.83	3.13	4.07	3.88	4.85	3.98	0.35			
Jan 2009 - Dec 2009	3.94	3.03	18.08	632.50	3.73	4.22	3.89	4.82	4.16	0.24			
Jan 2010 - Dec 2010	4.47	2.50	22.67	678.33	3.87	4.45	4.18	4.91	4.35	0.22			
Jan 2011 - Dec 2011	3.34	2.39	37.67	738.33	3.55	4.51	4.82	5.02	4.48	0.33			
Averages	**2.91**	**2.80**	**24.39**	**624.86**	**3.34**	**4.36**	**4.17**	**4.72**	**4.15**	**0.07**	**0.02**	**0.01**	**0.1840**

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

SUMMARY:

PAC = -1.39 ± 1.94 % per year
P-Value = 0.51

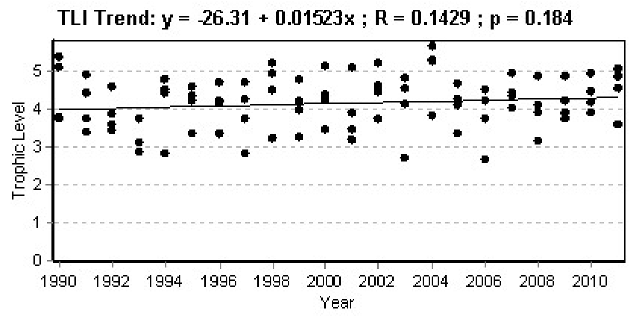
TLI Value = 4.15 ± 0.07 TLI units
TLI Trend = 0.02 ± 0.01 TLI units per year
P-Value = 0.1840

ASSESSMENT:

Eutrophic
No Change

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

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



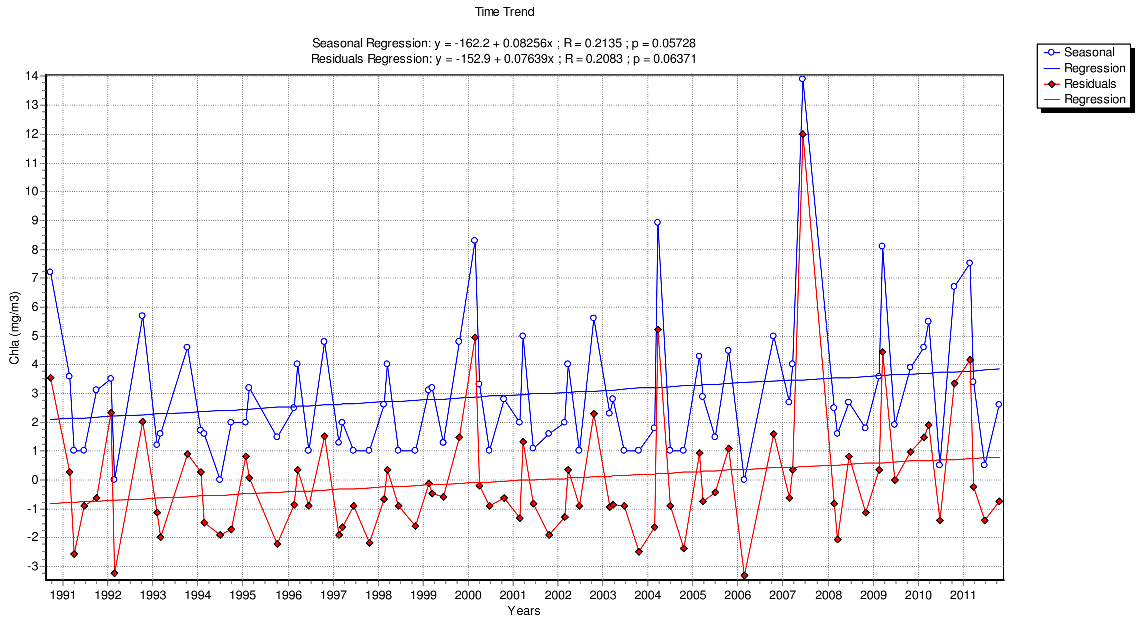
APPENDIX 1

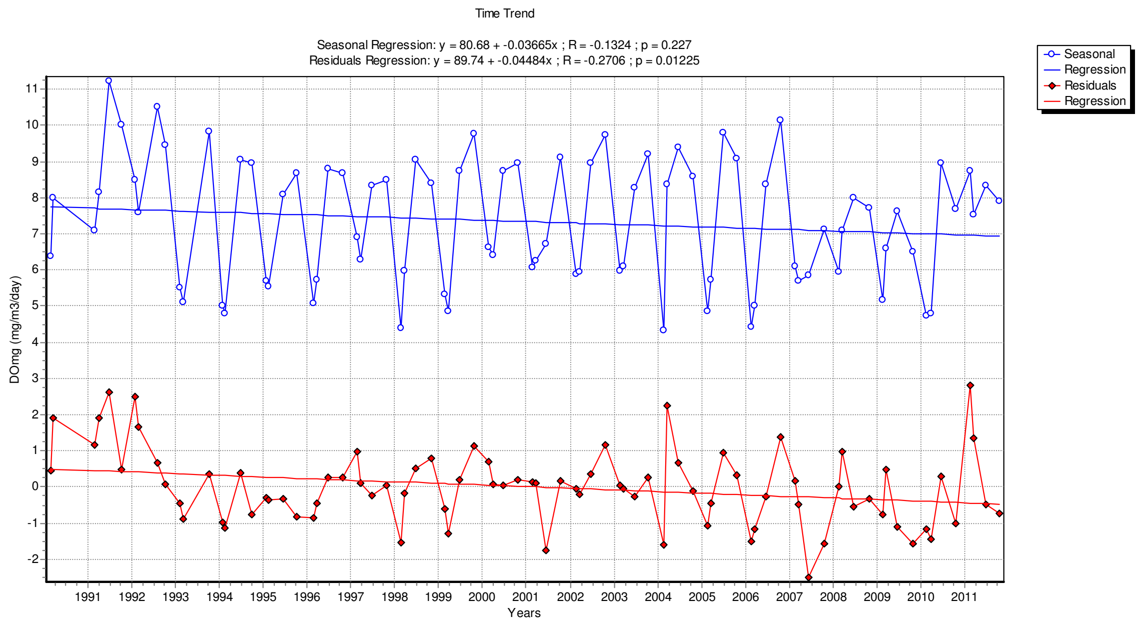
Table 3 p and R values for trend analysis of 1990-2011 data at sites L2 and L3 in Lake Rotorangi Values in orange = significant trend at $p<0.05$, values in red = significant trend at $p<0.01$.

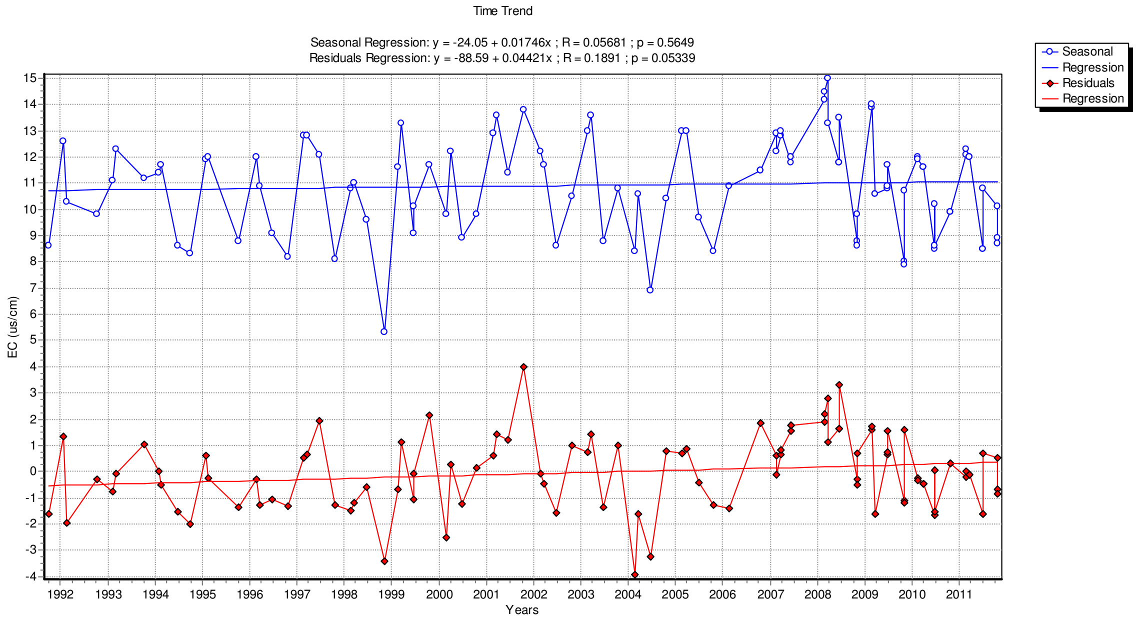
Parameter	**L2**		**L3**		**L2 & L3**	
	***p*-value**	**R**	***p*-value**	**R**	***p*-value**	**R**
Chlorophyll *a*	0.06	0.20	0.17	0.11	0.05	0.15
DO	0.01	-0.27	0.45	-0.08	0.06	-0.15
EC	0.05	0.19	0.36	0.09	0.05	0.14
Secchi Depth	0.36	0.10	0.22	-0.14	0.71	-0.029
TSS	0.19	-0.13	0.17	-0.13	0.11	-0.11
Temperature	0.32	-0.11	0.74	-0.04	0.36	-0.07
DRP	0.21	0.14	0.47	0.08	0.15	0.11
NH_4	0.80	0.03	0.72	0.04	0.70	0.03
NO_3	0.005	0.29	0.003	0.31	0.00005	0.3
TN	0.34	0.10	0.87	0.02	0.42	0.06
TP	0.65	-0.05	0.91	-0.01	0.67	-0.03
HVOD	0.65	0.12	0.44	-0.2	0.6	-0.13
TLI	0.39	0.09	0.21	0.16	0.18	0.14

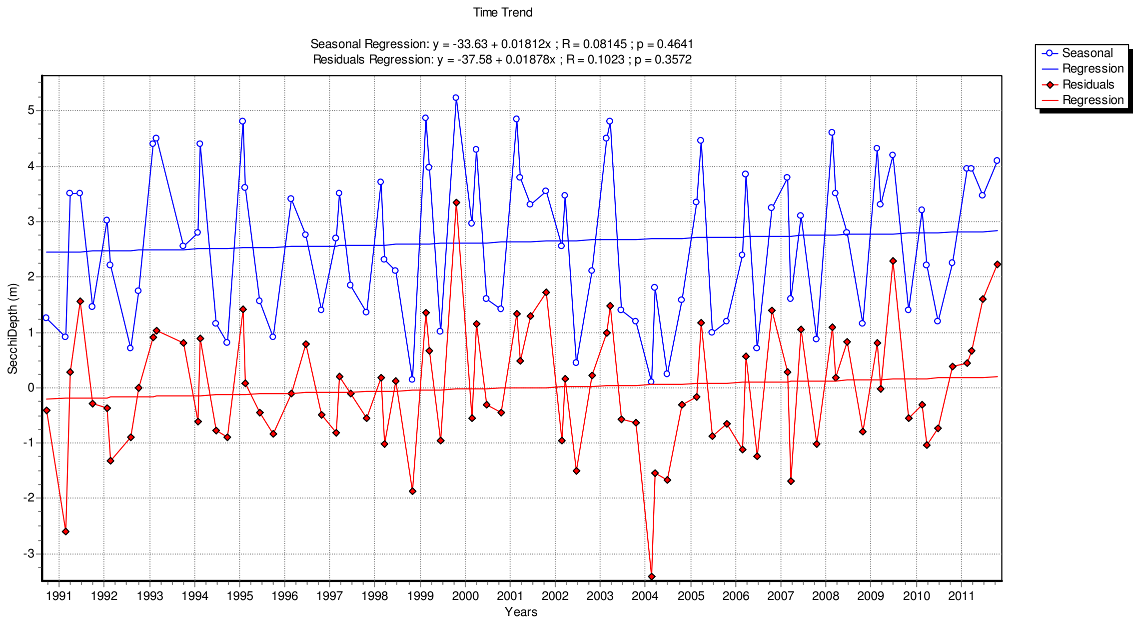
APPENDIX 2 Site L2 Trends

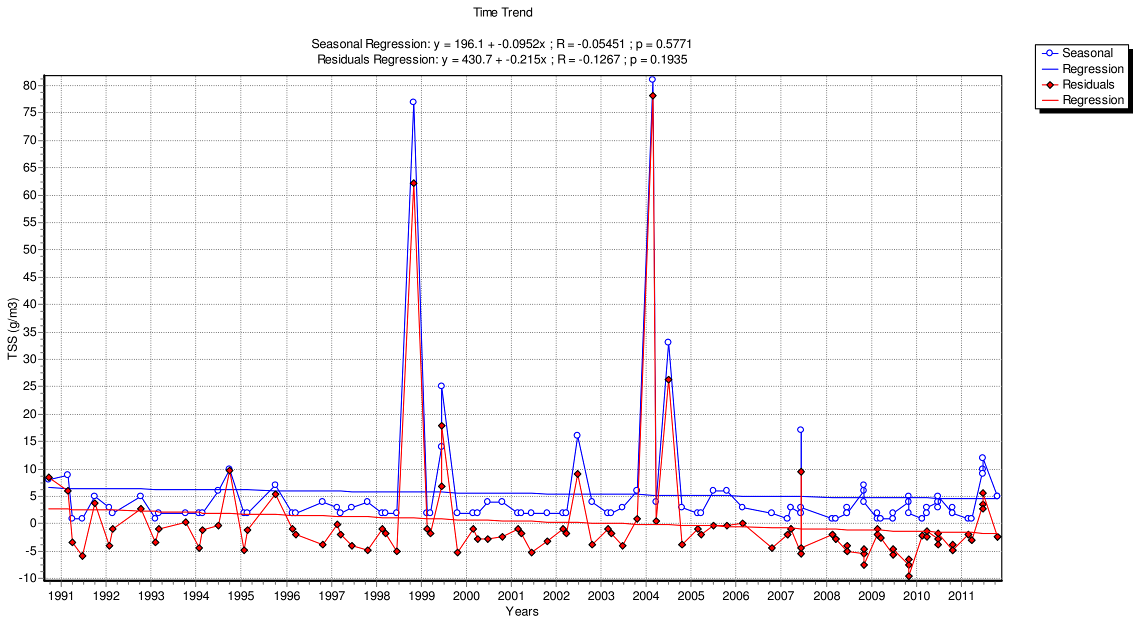
Physical Parameters

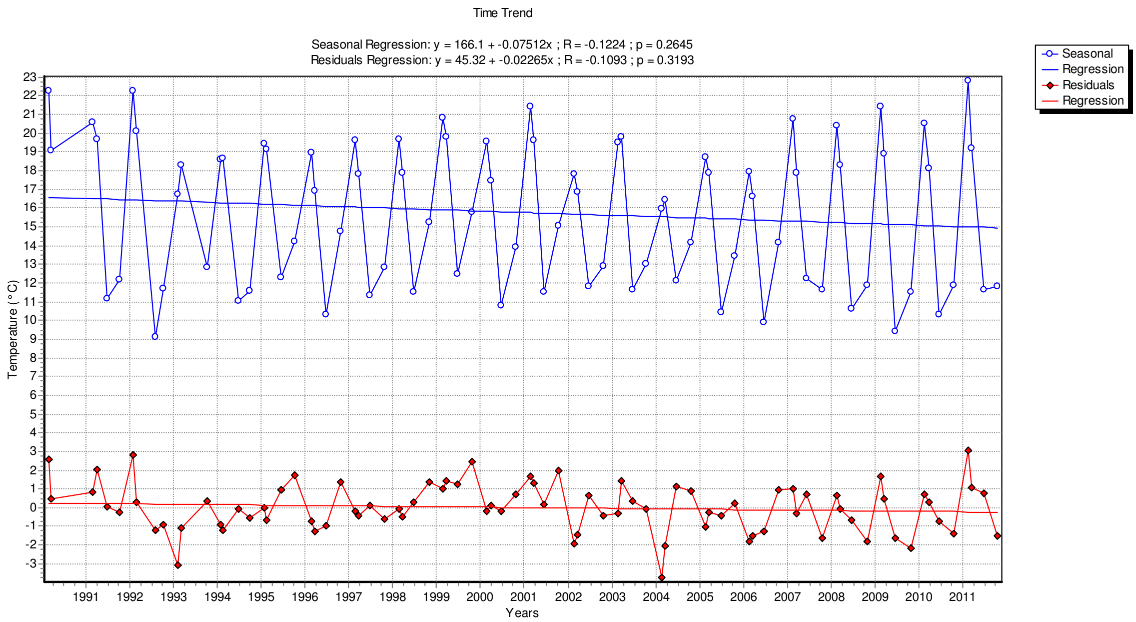




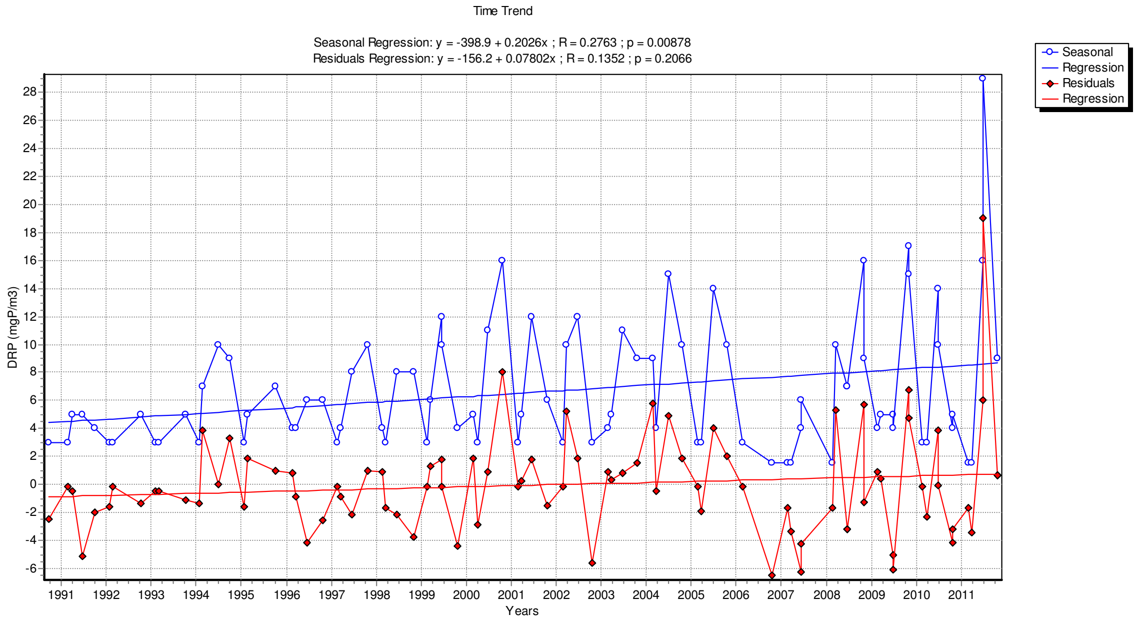

Time Trend
Seasonal Regression: y = -24.05 + 0.01746x ; R = 0.05681 ; p = 0.5649
Residuals Regression: y = -88.59 + 0.04421x ; R = 0.1891 ; p = 0.05339
EC (us/cm)
Years
Seasonal
Regression
Residuals
Regression


Time Trend
Seasonal Regression: y = -33.63 + 0.01812x ; R = 0.08145 ; p = 0.4641
Residuals Regression: y = -37.58 + 0.01878x ; R = 0.1023 ; p = 0.3572
SecchiDepth (m)
Years
Seasonal
Regression
Residuals
Regression

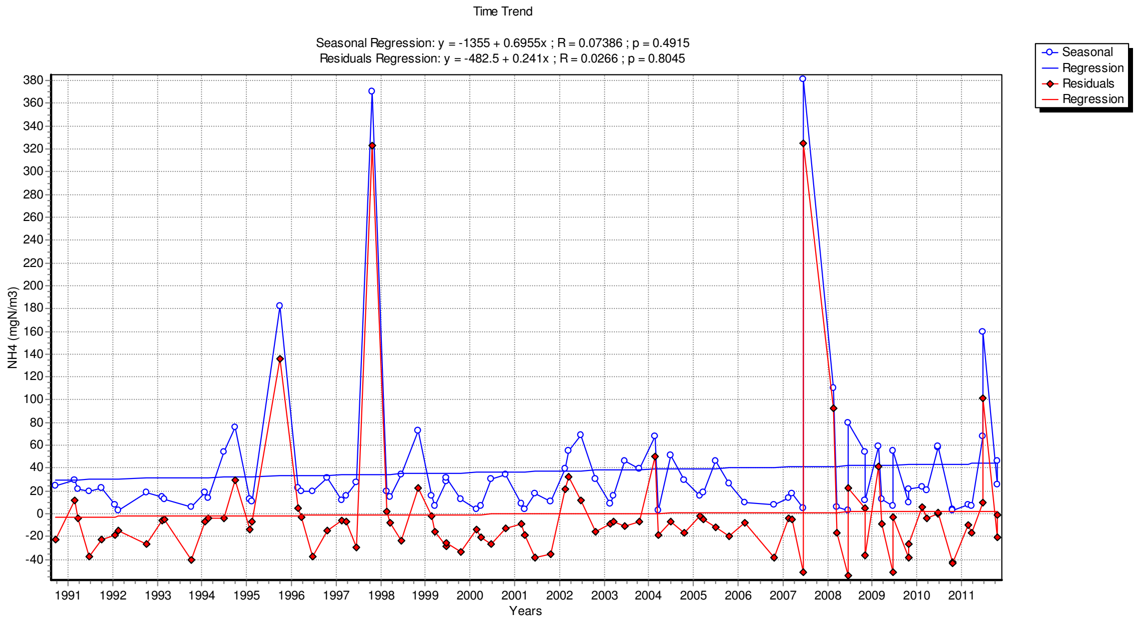

Time Trend
Seasonal Regression: y = 196.1 + -0.0952x ; R = -0.05451 ; p = 0.5771
Residuals Regression: y = 430.7 + -0.215x ; R = -0.1267 ; p = 0.1935
TSS (g/m3)
Years
Seasonal
Regression
Residuals
Regression


Time Trend
Seasonal Regression: y = 166.1 + -0.07512x ; R = -0.1224 ; p = 0.2645
Residuals Regression: y = 45.32 + -0.02265x ; R = -0.1093 ; p = 0.3193
Temperature (° C)
Years
Seasonal
Regression
Residuals
Regression

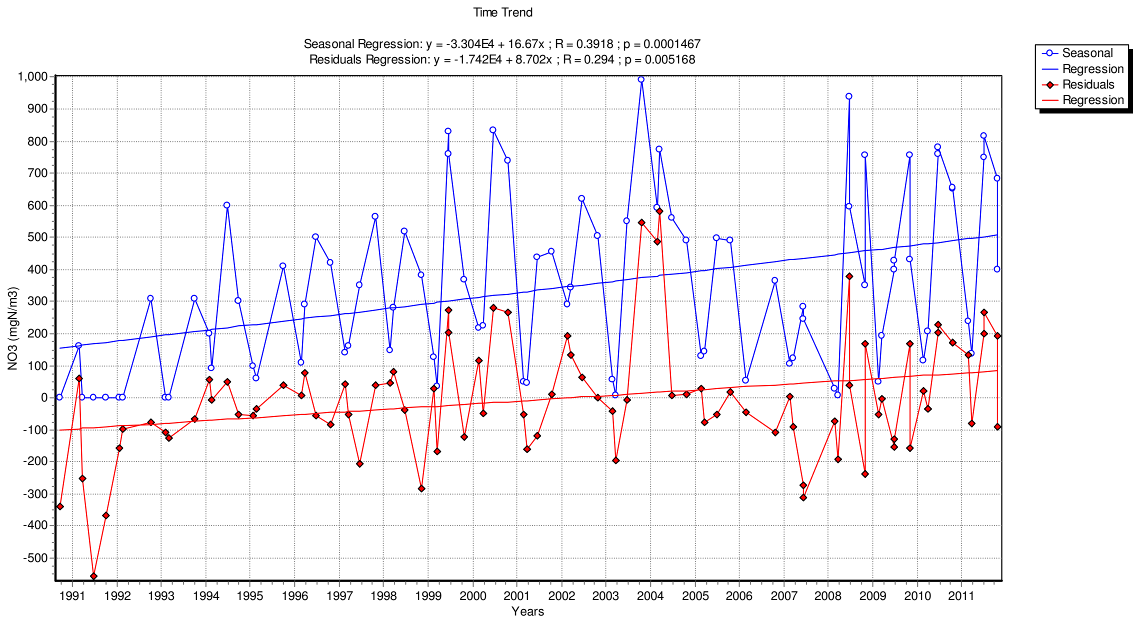
Nutrients

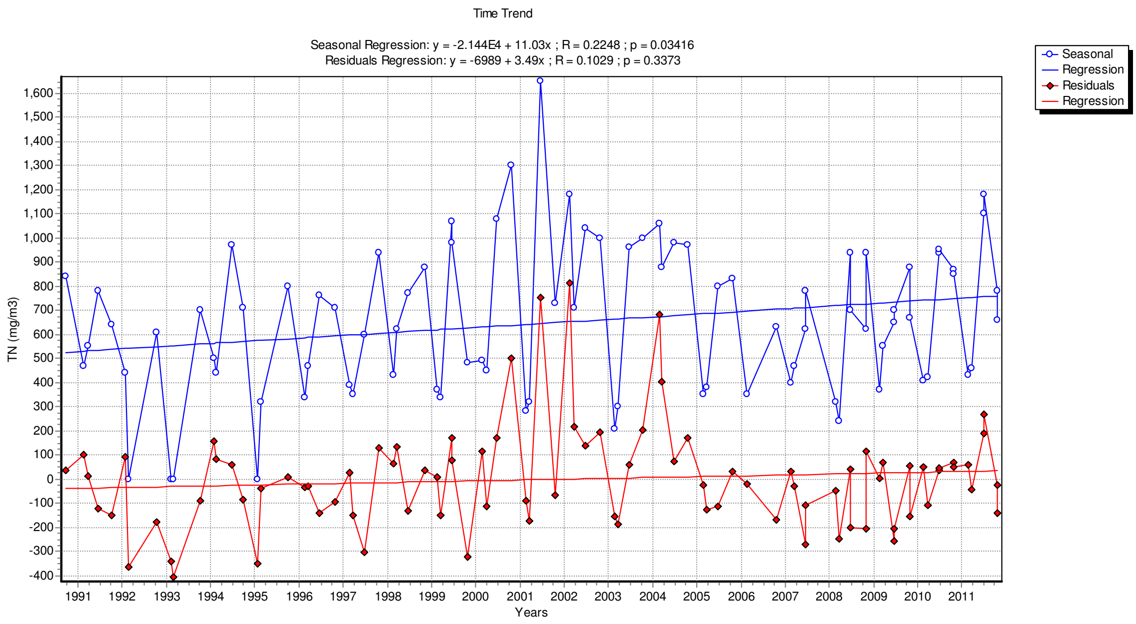


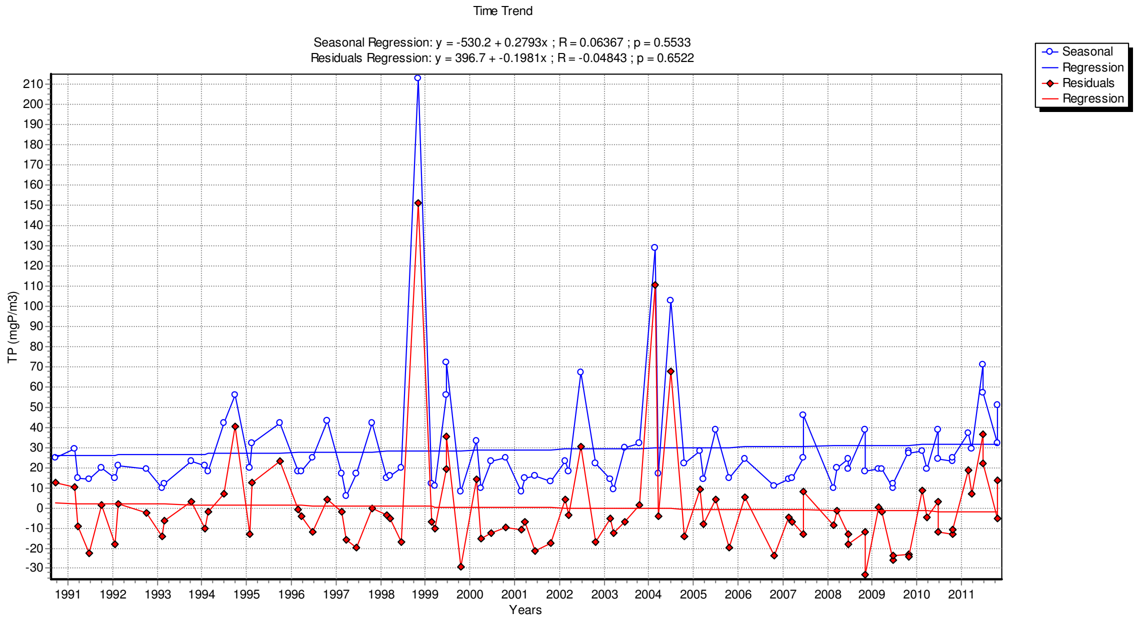
Time Trend
Seasonal Regression: y = -398.9 + 0.2026x ; R = 0.2763 ; p = 0.00878
Residuals Regression: y = -156.2 + 0.07802x ; R = 0.1352 ; p = 0.2066
Seasonal
Regression
Residuals
Regression
DRP (mgP/m3)
Years



Time Trend
Seasonal Regression: y = -1355 + 0.6955x ; R = 0.07386 ; p = 0.4915
Residuals Regression: y = -482.5 + 0.241x ; R = 0.0266 ; p = 0.8045
Seasonal
Regression
Residuals
Regression
NH4 (mgN/m3)
Years


Time Trend
Seasonal Regression: y = -3.304E4 + 16.67x ; R = 0.3918 ; p = 0.0001467
Residuals Regression: y = -1.742E4 + 8.702x ; R = 0.294 ; p = 0.005168
NO3 (mgN/m3)
Years
Seasonal
Regression
Residuals
Regression


Time Trend
Seasonal Regression: y = -2.144E4 + 11.03x ; R = 0.2248 ; p = 0.03416
Residuals Regression: y = -6989 + 3.49x ; R = 0.1029 ; p = 0.3373
TN (mg/m3)
Years
Seasonal
Regression
Residuals
Regression


Time Trend
Seasonal Regression: y = -530.2 + 0.2793x ; R = 0.06367 ; p = 0.5533
Residuals Regression: y = 396.7 + -0.1981x ; R = -0.04843 ; p = 0.6522
Seasonal
Regression
Residuals
Regression
TP (mgP/m3)
Years
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011

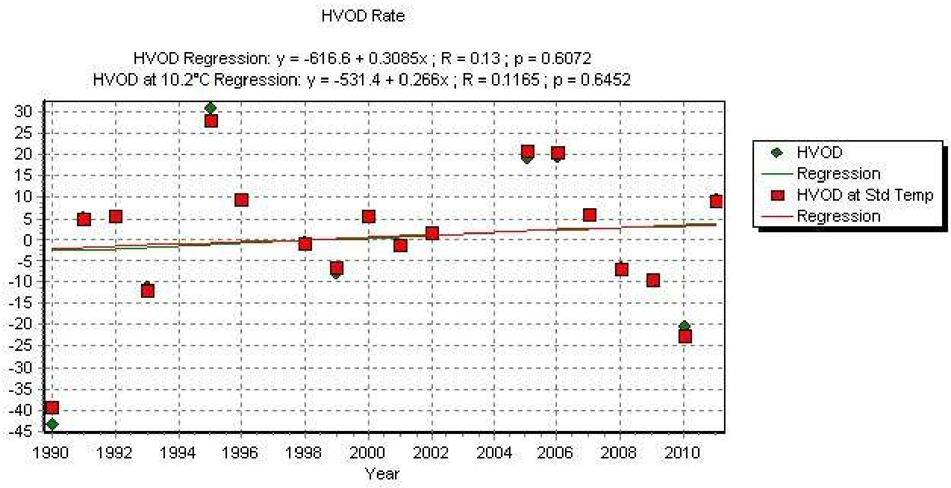
HVOD Analysis

Lake: LAKE ROTORANGI

Stations: L2 (Tangahoe Valley Rd)

Date From: 01/01/1990 **Date To:** 01/01/2012

Analysis Period	Average	Observed DO	Observed Rate Corrected to 10.2 °C (mg/m3/day)
01-Jan-1990 - 31-Mar-1990	11.7	-43.3	-39.0
01-Jan-1991 - 31-Mar-1991	11.58	5.1	4.7
01-Jan-1992 - 30-Mar-1992	9.94	5.6	5.7
01-Jan-1993 - 31-Mar-1993	9.4	-11.2	-11.8
01-Jan-1995 - 31-Mar-1995	11.58	30.7	27.9
01-Jan-1996 - 30-Mar-1996	9.29	8.9	9.5
01-Jan-1998 - 31-Mar-1998	8.53	-0.6	-0.7
01-Jan-1999 - 31-Mar-1999	13.14	-7.9	-6.4
01-Jan-2000 - 04-Apr-2000	10.23	5.4	5.4
01-Jan-2001 - 31-Mar-2001	10.78	-1.1	-1.1
01-Jan-2002 - 31-Mar-2002	8.86	1.4	1.5
01-Jan-2005 - 31-Mar-2005	9.03	19.0	20.7
01-Jan-2006 - 31-Mar-2006	9.51	19.4	20.4
01-Jan-2007 - 31-Mar-2007	10.04	5.8	5.9
01-Jan-2008 - 30-Mar-2008	9.73	-6.5	-6.7
01-Jan-2009 - 31-Mar-2009	10.36	-9.4	-9.3
01-Jan-2010 - 31-Mar-2010	8.96	-20.4	-22.3
01-Jan-2011 - 31-Mar-2011	10.63	9.5	9.2
Average	**10.18**	**0.6**	**0.8**



LAKE ROTORANGI

L2 1990-2011 (1 Jan 1990 - 31 Dec 2011)

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	(0.08)	(0.02)	(-0.20)	(3.49)	1.40			
Average Over Period	(2.98)	(2.64)	(29.02)	(652.81)	-19.93			
Percent Annual Change (%/Year)	**0.00**	**0.00**	**0.00**	**0.00**	**-7.02**	**-1.40**	**1.40**	**0.37**

Burns 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
Jan 1990 - Dec 1990	7.20	1.25	25.00	840.00	4.40	5.27	4.30	5.19	4.79	0.26			
Jan 1991 - Dec 1991	2.17	2.34	19.50	610.00	3.08	4.53	3.98	4.77	4.09	0.38			
Jan 1992 - Dec 1992	3.07	1.92	18.33	350.00	3.46	4.77	3.91	4.05	4.04	0.27			
Jan 1993 - Dec 1993	2.47	3.82	15.00	233.33	3.22	3.93	3.65	3.52	3.58	0.15			
Jan 1994 - Dec 1994	1.33	2.29	34.25	655.00	2.53	4.56	4.70	4.87	4.16	0.55			
Jan 1995 - Dec 1995	2.23	2.71	31.33	373.33	3.11	4.35	4.59	4.13	4.04	0.33			
Jan 1996 - Dec 1996	3.08	2.52	26.00	570.00	3.46	4.44	4.35	4.69	4.23	0.27			
Jan 1997 - Dec 1997	1.32	2.35	20.50	570.00	2.53	4.53	4.05	4.69	3.95	0.49			
Jan 1998 - Dec 1998	2.15	2.06	66.00	675.00	3.06	4.68	5.53	4.91	4.55	0.53			
Jan 1999 - Dec 1999	2.74	3.77	31.80	648.00	3.33	3.95	4.61	4.85	4.18	0.34			
Jan 2000 - Dec 2000	3.85	2.57	22.75	830.00	3.71	4.42	4.18	5.18	4.37	0.31			
Jan 2001 - Dec 2001	2.43	3.87	13.00	745.00	3.20	3.92	3.47	5.04	3.90	0.40			
Jan 2002 - Dec 2002	3.15	2.14	32.50	982.50	3.49	4.64	4.63	5.40	4.54	0.39			
Jan 2003 - Dec 2003	1.77	2.98	21.25	617.50	2.85	4.24	4.09	4.79	3.99	0.41			
Jan 2004 - Dec 2004	3.17	0.93	67.75	972.50	3.49	5.62	5.56	5.38	5.02	0.51			
Jan 2005 - Dec 2005	3.30	2.50	24.00	590.00	3.54	4.45	4.25	4.73	4.24	0.25			
Jan 2006 - Dec 2006	2.50	2.55	17.50	490.00	3.23	4.43	3.85	4.49	4.00	0.29			
Jan 2007 - Dec 2007	5.27	2.34	28.17	730.00	4.05	4.53	4.45	5.01	4.51	0.20			
Jan 2008 - Dec 2008	2.15	3.01	21.67	626.67	3.06	4.23	4.12	4.81	4.05	0.36			
Jan 2009 - Dec 2009	4.38	3.30	19.17	636.67	3.85	4.11	3.96	4.83	4.19	0.22			
Jan 2010 - Dec 2010	4.32	2.21	26.33	740.00	3.84	4.60	4.37	5.03	4.46	0.25			
Jan 2011 - Dec 2011	3.50	3.87	46.17	768.33	3.60	3.92	5.08	5.08	4.42	0.39			
Averages	**3.07**	**2.60**	**28.54**	**647.90**	**3.37**	**4.46**	**4.35**	**4.79**	**4.24**	**0.07**	**0.01**	**0.01**	**0.3892**

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

SUMMARY:

PAC = -1.40 ± 1.40 % per year
P-Value = 0.37

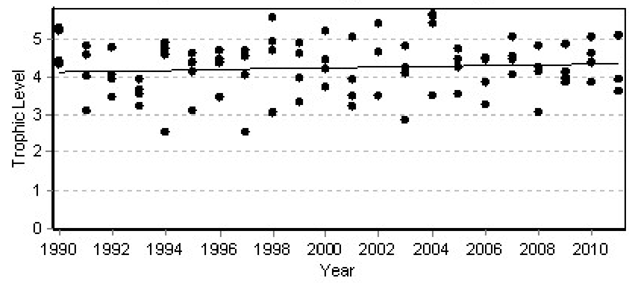
TLI Value = 4.24 ± 0.07 TLI units
TLI Trend = 0.01 ± 0.01 TLI units per year
P-Value = 0.3892

ASSESSMENT:

Eutrophic
No Change

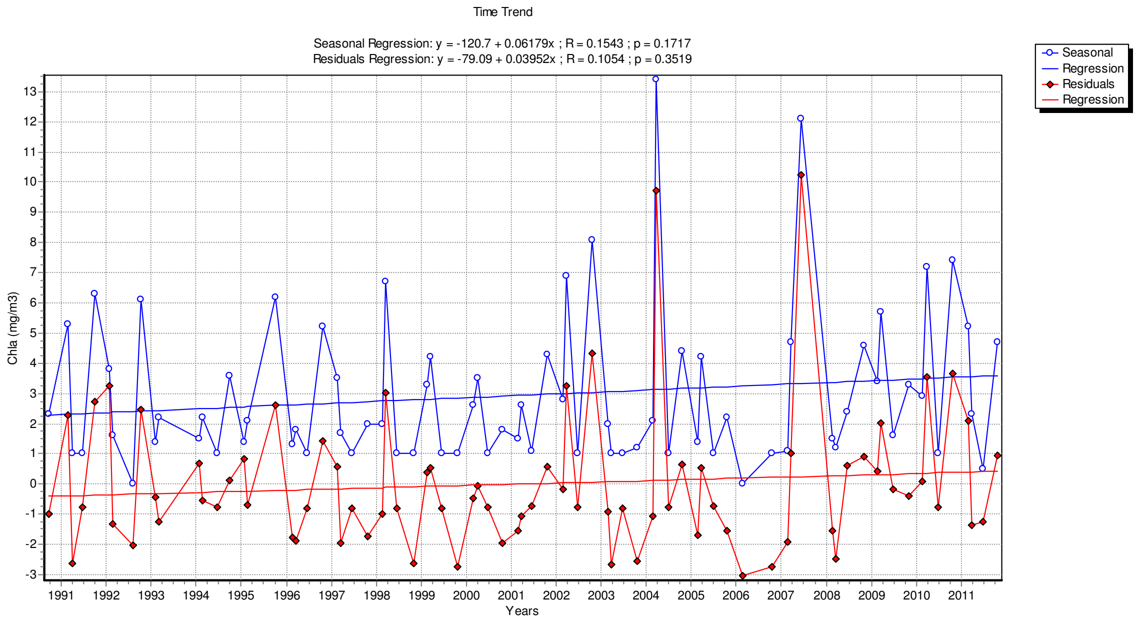
The guide used in the PAC average P-Value evaluation is

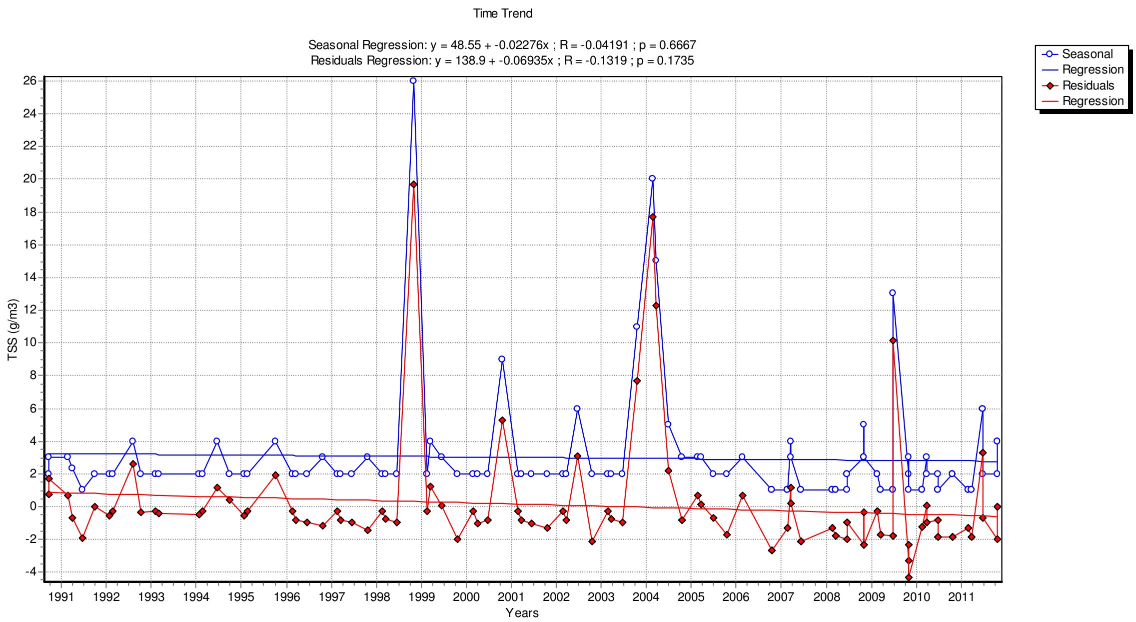
P-Value Range	Interpretation
P ≤ 0.1	Definite Change
0.1 < P ≤ 0.2	Probable Change
0.2 < P ≤ 0.3	Possible Change
0.3 < P	No Change

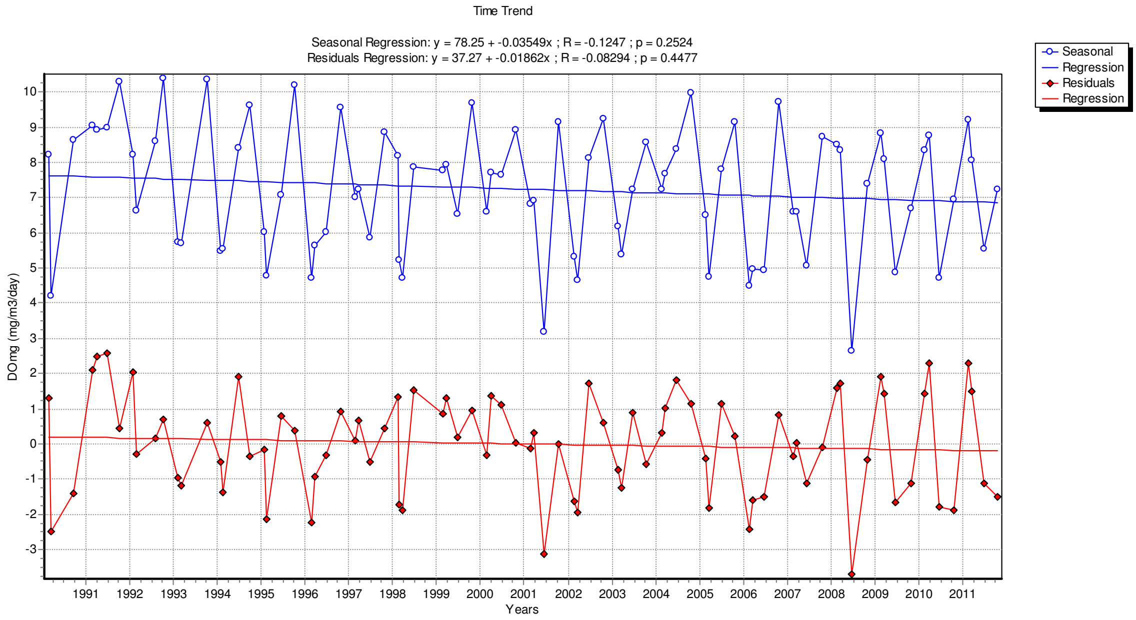


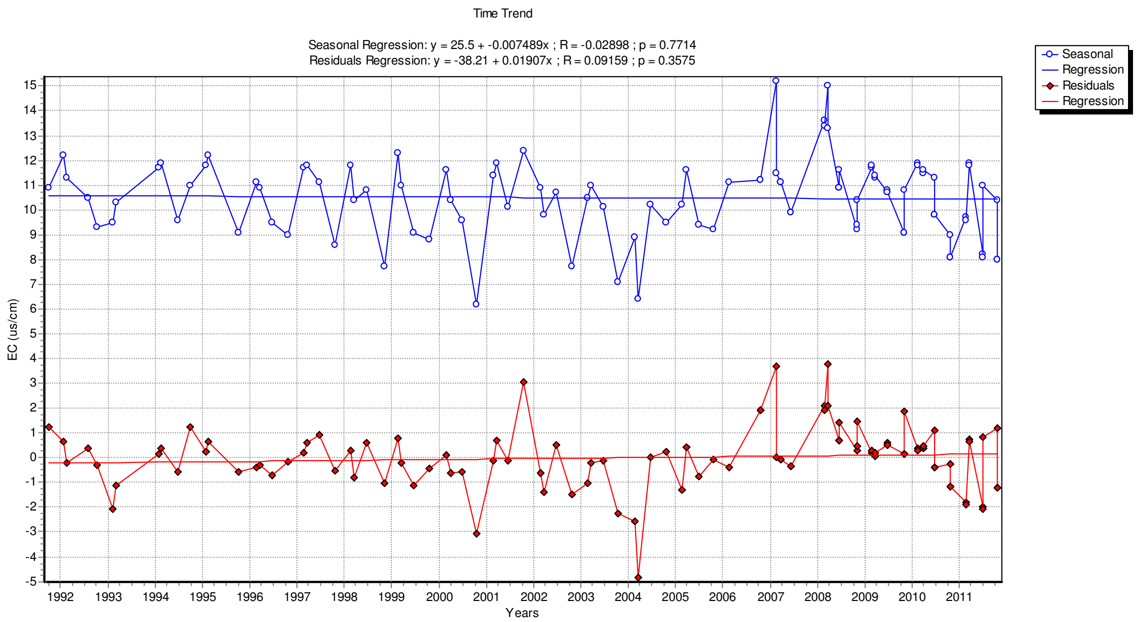
Appendix 3   Site L3 Trends

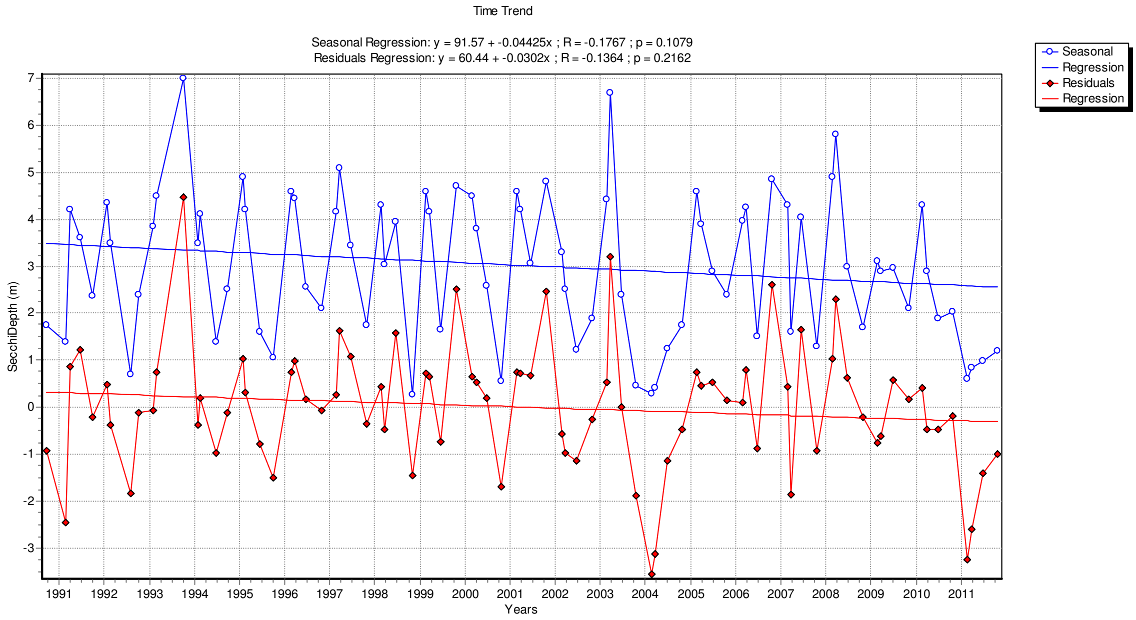
Physical parameters

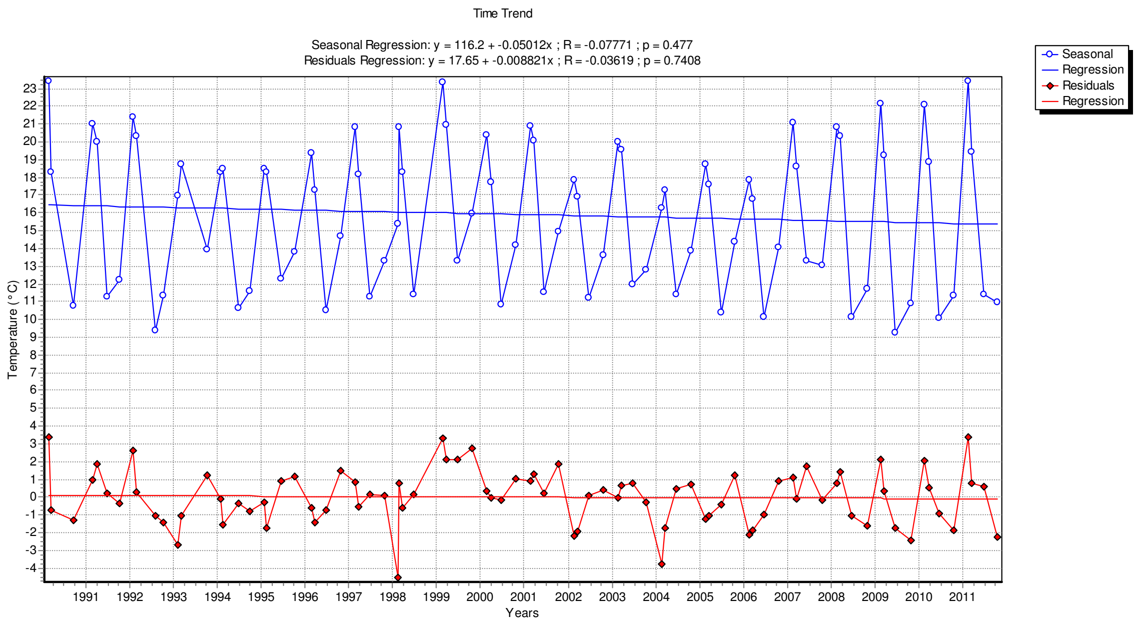




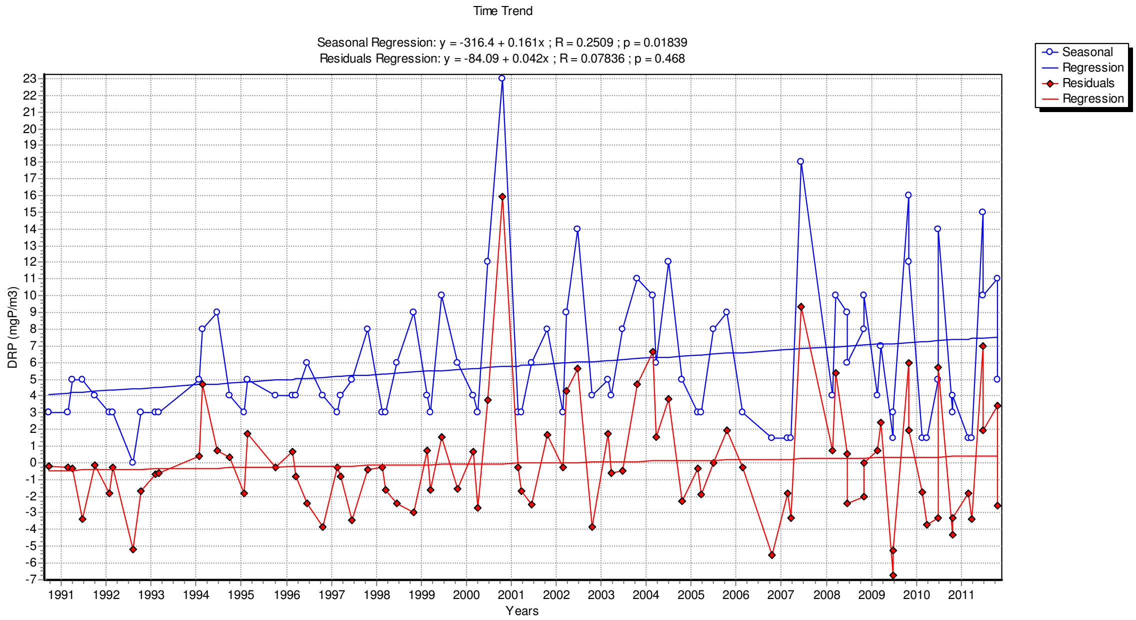

Time Trend
Seasonal Regression: y = 78.25 + -0.03549x ; R = -0.1247 ; p = 0.2524
Residuals Regression: y = 37.27 + -0.01862x ; R = -0.08294 ; p = 0.4477
Seasonal
Regression
Residuals
Regression
DOmg (mg/m3/day)
Years

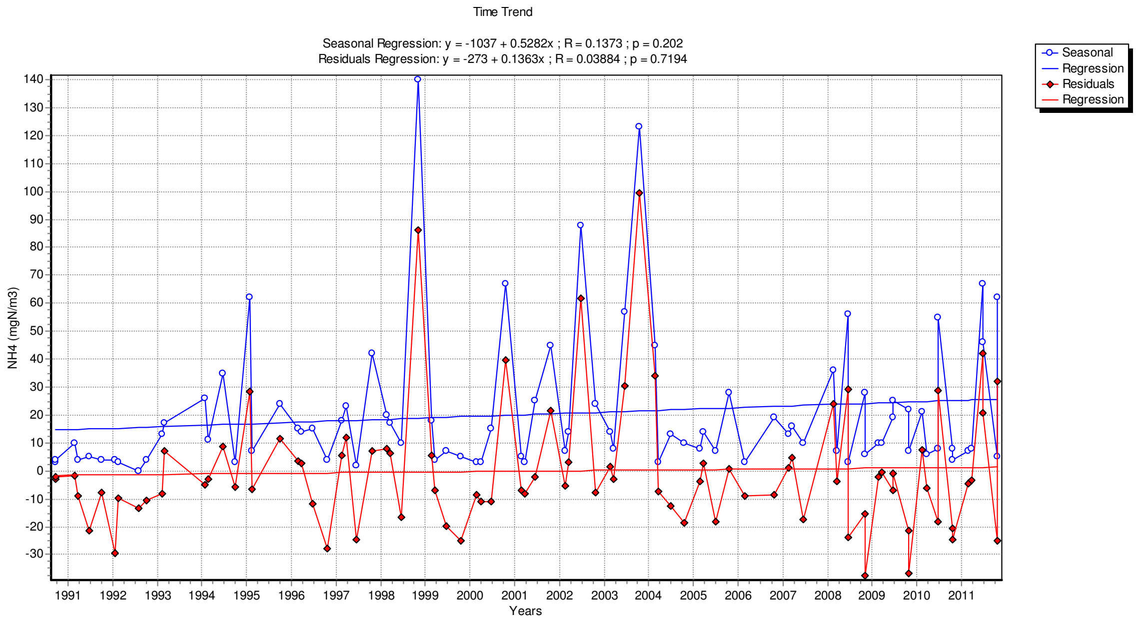

Time Trend
Seasonal Regression: y = 25.5 + -0.007489x ; R = -0.02898 ; p = 0.7714
Residuals Regression: y = -38.21 + 0.01907x ; R = 0.09159 ; p = 0.3575
Seasonal
Regression
Residuals
Regression
EC (us/cm)
Years

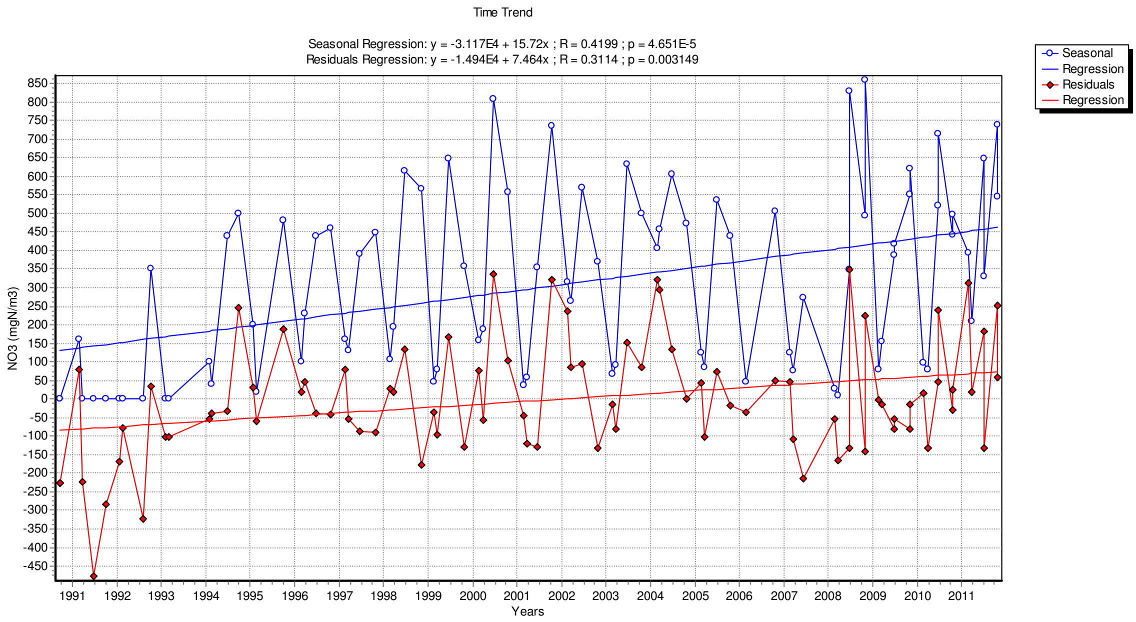

Time Trend
Seasonal Regression: y = 91.57 + -0.04425x ; R = -0.1767 ; p = 0.1079
Residuals Regression: y = 60.44 + -0.0302x ; R = -0.1364 ; p = 0.2162
Seasonal
Regression
Residuals
Regression
SecchiDepth (m)
Years

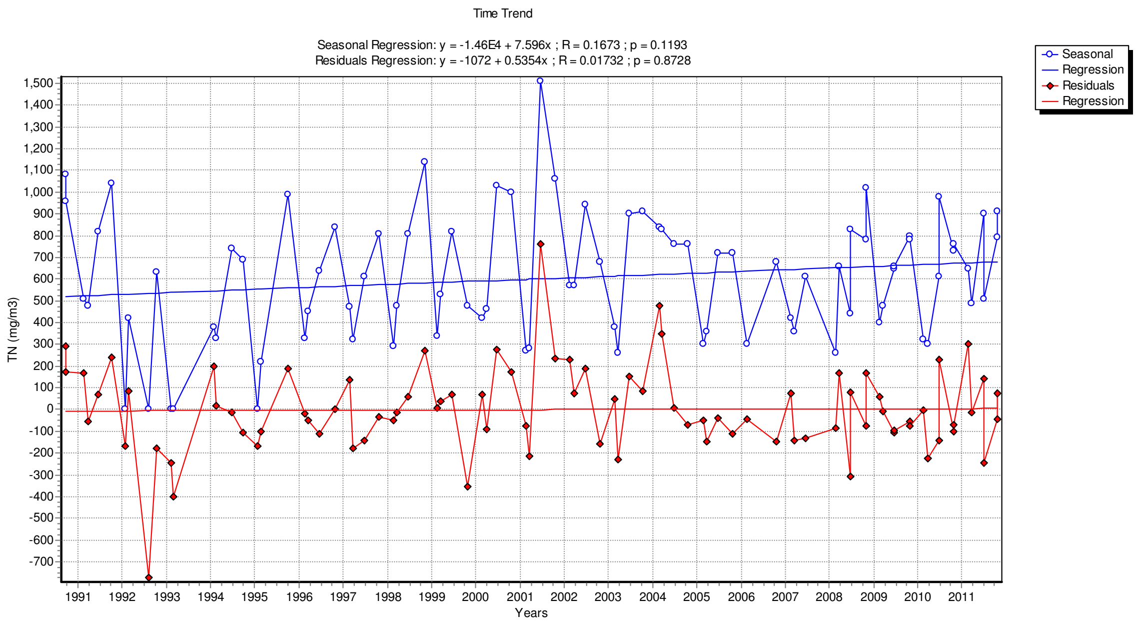

Time Trend
Seasonal Regression: y = 116.2 + -0.05012x ; R = -0.07771 ; p = 0.477
Residuals Regression: y = 17.65 + -0.008821x ; R = -0.03619 ; p = 0.7408
Seasonal
Regression
Residuals
Regression
Temperature (°C)
Years

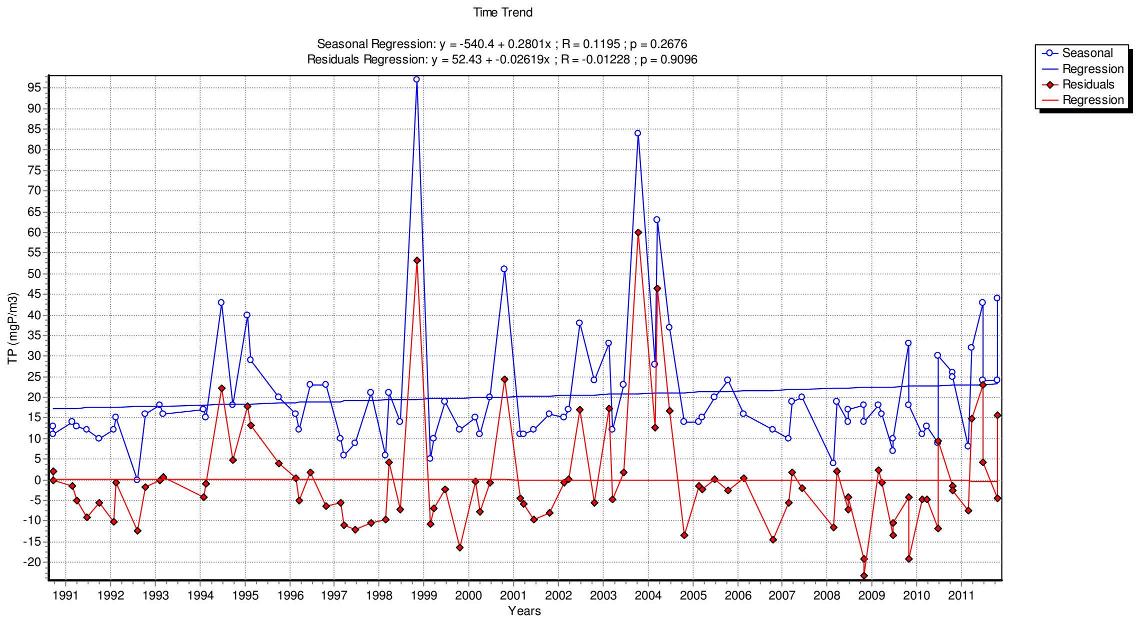
Nutrients


Time Trend
Seasonal Regression: y = -316.4 + 0.161x ; R = 0.2509 ; p = 0.01839
Residuals Regression: y = -84.09 + 0.042x ; R = 0.07836 ; p = 0.468
DRP (mgP/m3)
Years
Seasonal
Regression
Residuals
Regression


Time Trend
Seasonal Regression: y = -1037 + 0.5282x ; R = 0.1373 ; p = 0.202
Residuals Regression: y = -273 + 0.1363x ; R = 0.03884 ; p = 0.7194
NH4 (mgN/m3)
Years
Seasonal
Regression
Residuals
Regression


Time Trend
Seasonal Regression: y = -3.117E4 + 15.72x ; R = 0.4199 ; p = 4.651E-5
Residuals Regression: y = -1.494E4 + 7.464x ; R = 0.3114 ; p = 0.003149
Seasonal
Regression
Residuals
Regression
NO3 (mgN/m3)
Years


Time Trend
Seasonal Regression: y = -1.46E4 + 7.596x ; R = 0.1673 ; p = 0.1193
Residuals Regression: y = -1072 + 0.5354x ; R = 0.01732 ; p = 0.8728
Seasonal
Regression
Residuals
Regression
TN (mg/m3)
Years



Time Trend
Seasonal Regression: y = -540.4 + 0.2801x ; R = 0.1195 ; p = 0.2676
Residuals Regression: y = 52.43 + -0.02619x ; R = -0.01228 ; p = 0.9096
Seasonal
Regression
Residuals
Regression
TP (mgP/m3)
Years

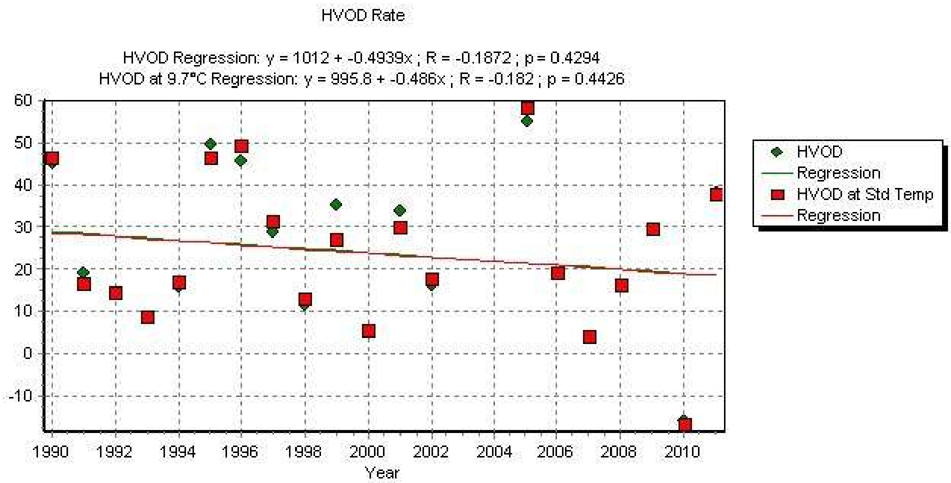
HVOD Analysis

Lake: LAKE ROTORANGI

Stations: L3 (Dam)

Date From: 01/01/1990 **Date To:** 01/01/2012

Analysis Period	Average	Observed DO	Observed Rate Corrected to 9.7 °C (mg/m3/day)
01-Jan-1990 - 31-Mar-1990	9.31	45.4	46.6
01-Jan-1991 - 31-Mar-1991	11.6	19.4	17.0
01-Jan-1992 - 30-Mar-1992	9.76	14.6	14.6
01-Jan-1993 - 31-Mar-1993	9.4	8.8	9.0
01-Jan-1994 - 31-Mar-1994	8.62	16.1	17.4
01-Jan-1995 - 31-Mar-1995	10.62	49.8	46.7
01-Jan-1996 - 30-Mar-1996	8.59	45.7	49.3
01-Jan-1997 - 31-Mar-1997	8.51	29.1	31.6
01-Jan-1998 - 31-Mar-1998	8.09	11.8	13.2
01-Jan-1999 - 31-Mar-1999	13.49	35.3	27.2
01-Jan-2000 - 04-Apr-2000	10.0	5.8	5.7
01-Jan-2001 - 31-Mar-2001	11.39	34.0	30.2
01-Jan-2002 - 31-Mar-2002	8.6	16.5	17.8
01-Jan-2005 - 31-Mar-2005	8.86	55.0	58.3
01-Jan-2006 - 31-Mar-2006	9.34	18.8	19.3
01-Jan-2007 - 31-Mar-2007	10.33	4.5	4.3
01-Jan-2008 - 30-Mar-2008	9.25	16.0	16.6
01-Jan-2009 - 31-Mar-2009	9.76	29.9	29.7
01-Jan-2010 - 31-Mar-2010	8.98	-15.6	-16.4
01-Jan-2011 - 31-Mar-2011	9.88	38.4	38.0
Average	**9.72**	**24.0**	**23.8**



LAKE ROTORANGI

L3 1990-2012 (1 Jan 1990 - 1 Jan 2012)

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	(0.04)	(-0.03)	(-0.03)	(0.54)	(-0.49)			
Average Over Period	(2.94)	(3.01)	(20.43)	(605.23)	(23.80)			
Percent Annual Change (%/Year)	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**1.00**

Burns 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
Jan 1990 - Dec 1990	2.30	1.75	12.00	1,020.00	3.14	4.88	3.37		3.80	0.55			
Jan 1991 - Dec 1991	3.40	2.89	12.25	712.50	3.57	4.28	3.40		3.75	0.27			
Jan 1992 - Dec 1992	2.87	2.74	10.75	262.50	3.38	4.34	3.23		3.65	0.35			
Jan 1993 - Dec 1993	1.80	5.12	17.00	0.00	2.87	3.56	3.81		3.41	0.28			
Jan 1994 - Dec 1994	2.07	2.87	23.25	535.00	3.03	4.28	4.21		3.84	0.41			
Jan 1995 - Dec 1995	3.23	2.94	29.67	403.33	3.51	4.26	4.52		4.10	0.30			
Jan 1996 - Dec 1996	2.32	3.42	18.50	565.00	3.15	4.07	3.92		3.71	0.28			
Jan 1997 - Dec 1997	2.05	3.61	11.50	552.50	3.01	4.00	3.32		3.44	0.29			
Jan 1998 - Dec 1998	2.67	2.89	34.50	680.00	3.31	4.28	4.71		4.10	0.42			
Jan 1999 - Dec 1999	2.37	3.77	11.50	542.50	3.17	3.95	3.32		3.48	0.24			
Jan 2000 - Dec 2000	2.22	2.86	24.25	727.50	3.10	4.29	4.26		3.88	0.39			
Jan 2001 - Dec 2001	2.38	4.16	12.50	780.00	3.17	3.83	3.42		3.47	0.19			
Jan 2002 - Dec 2002	4.70	2.23	23.50	690.00	3.93	4.59	4.22		4.25	0.19			
Jan 2003 - Dec 2003	1.30	3.49	38.00	612.50	2.51	4.05	4.83		3.80	0.68			
Jan 2004 - Dec 2004	5.22	0.92	35.50	797.50	4.04	5.63	4.74		4.81	0.46			
Jan 2005 - Dec 2005	2.20	3.45	18.25	525.00	3.09	4.06	3.90		3.68	0.30			
Jan 2006 - Dec 2006	0.50	3.64	14.00	490.00	1.46	3.99	3.56		3.00	0.78			
Jan 2007 - Dec 2007	4.75	2.81	21.00	592.50	3.94	4.31	4.08		4.11	0.11			
Jan 2008 - Dec 2008	2.43	3.85	14.33	665.00	3.20	3.92	3.59		3.57	0.21			
Jan 2009 - Dec 2009	3.50	2.76	17.00	628.33	3.60	4.33	3.81		3.91	0.22			
Jan 2010 - Dec 2010	4.63	2.79	19.00	616.67	3.91	4.32	3.95		4.06	0.13			
Jan 2011 - Dec 2011	3.17	0.91	29.17	708.33	3.49	5.64	4.50		4.54	0.62			
Averages	**2.82**	**2.99**	**20.34**	**595.76**	**3.25**	**4.31**	**3.94**		**3.83**	**0.08**	**0.02**	**0.01**	**0.2055**

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

SUMMARY:

PAC = 0.00 ± 0.00 % per year
P-Value = 1.00

TLI Value = 3.84 ± 0.08 TLI units
TLI Trend = 0.02 ± 0.01 TLI units per year
P-Value = 0.2055

ASSESSMENT:

Mesotrophic
No Change

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

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

TLI Trend: y = -29.71 + 0.01677x ; R = 0.1579 ; p = 0.2055