State of the Environment Monitoring of Lake Rotorangi water quality and biological programme Annual Report 2012-2013

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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 2012-2013 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 1990-2012) confirmed this very slow, insignificant rate of increase in trophic level.

Four water quality sampling surveys were performed during the 2012-2013 period, the first (spring) of which followed several recent freshes in the catchment which markedly 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 remained evident in 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 on most occasions to date.

During the monitoring year phytoplankton densities were 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.

A summer 2012 macrophyte survey had 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 macrophyte survey of Lake Rotorangi is due to be performed in the 2014-2015 period.

The monitoring programme will continue in its present format for state of the environment reporting purposes with regular (3-yearly) additional components (e.g. macrophyte survey) for consent compliance purposes.

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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 previous (2011-2012), and every third survey hereafter, will also be included 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 and one subsequent state of the environment report. 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 1990-2012 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 2013, some 199 riparian plans have been prepared by the TRC within the Patea River sub-catchment and three plans in the Mangaehu River sub-catchment upstream of the lake. Within these plans some 727km of Patea streambanks [61% of the total banks' length] and 12km of Mangaehu stream banks [29%] currently have adequate riparian protection provided on the dairying properties covered by the plans. This represents increases of 90km and 3km in these two sub-catchments over the past year. Outside of the properties covered by plans there are a further 54% and 98% 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 22 year period 1990-2012 (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 nitrate nitrogen.

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 three of the lake sampling visits (in conjunction with physicochemical sampling). Macroinvertebrate samples were collected from the substrate of the two sites during the spring physicochemical survey. The aquatic macrophyte survey of the lake last performed during autumn 2012, was not required until the 2014-2015 period.

1.5 Objective

The objective of this Annual Report is to present the results of the 2012-2013 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*

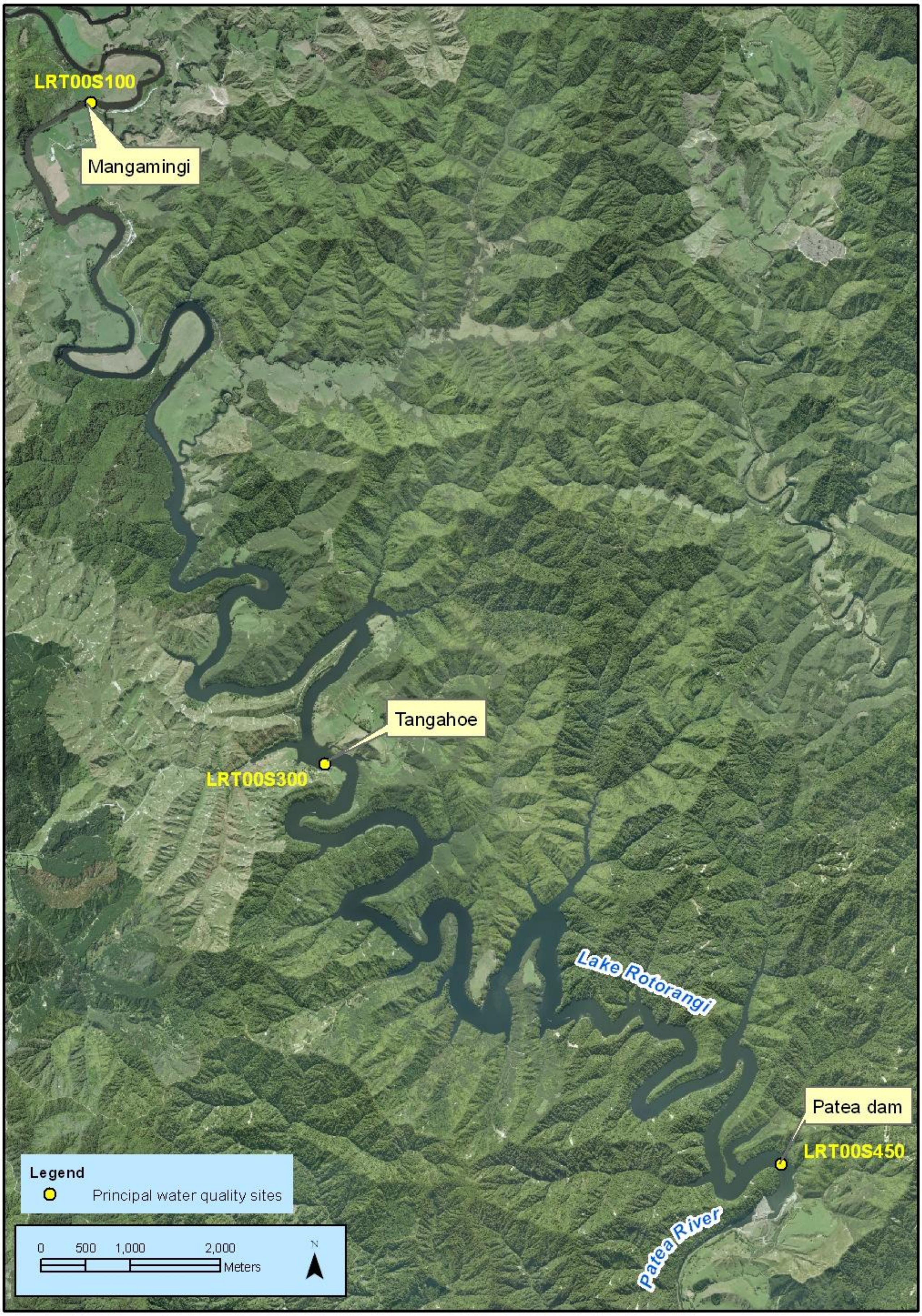


Figure 1 Aerial location map of Lake Rotorangi water quality sampling sites for 2012-2013 [LRT000300 and LRT000450].

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	25 October 2012
2	Late summer, stratification	21 February 2013
3	Autumn, stratification	20 March 2013
4	Winter	18 June 2013

The spring sampling survey was performed under steady flood recession river flow conditions following three river freshes over the preceding three weeks (see Figures 2 and 3 and Appendix I). The late summer survey occurred under very low river recession flow conditions following one fresh (two weeks earlier) during the previous month. The autumn survey was performed under steady fresh recession flow conditions two days after a fresh but seven weeks since the previous fresh. The final (winter) survey was performed during flood river flow conditions one day after two moderate river freshes, and after a wet period of nine freshes in both catchments over the preceding four weeks. Lake level was moderately high (76.5 m asl) at the time of the spring survey, high during the winter survey (77.1 m asl), and moderately high (76.8 m asl) during the late summer and during the autumn surveys (76.6 m asl).

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.

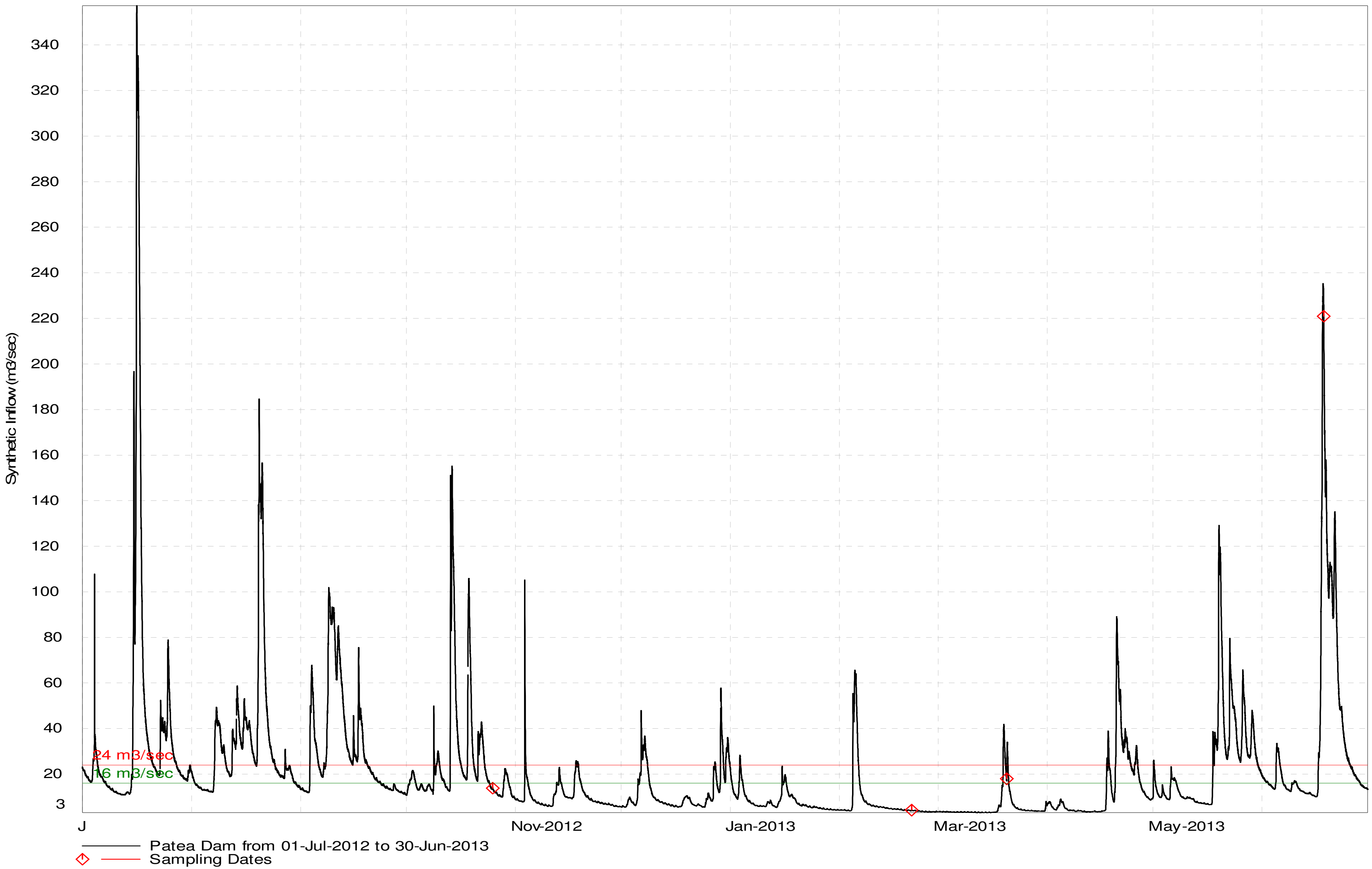


Figure 2 Synthesized hourly mean inflow at Lake Rotorangi for the period 1 July 2012 to 30 June 2013

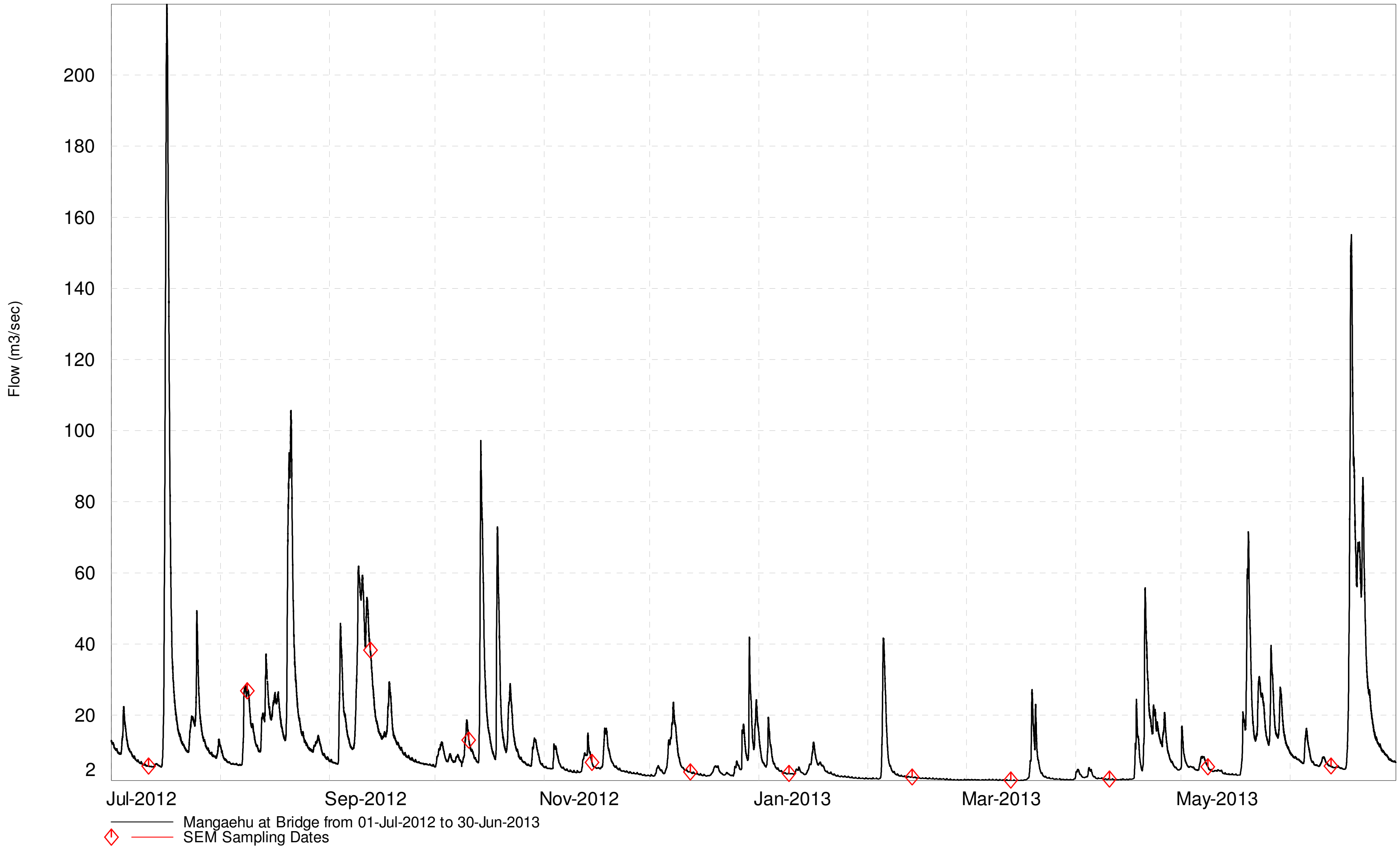


Figure 3 Flow in the Mangaehu River from July 2012 to June 2013

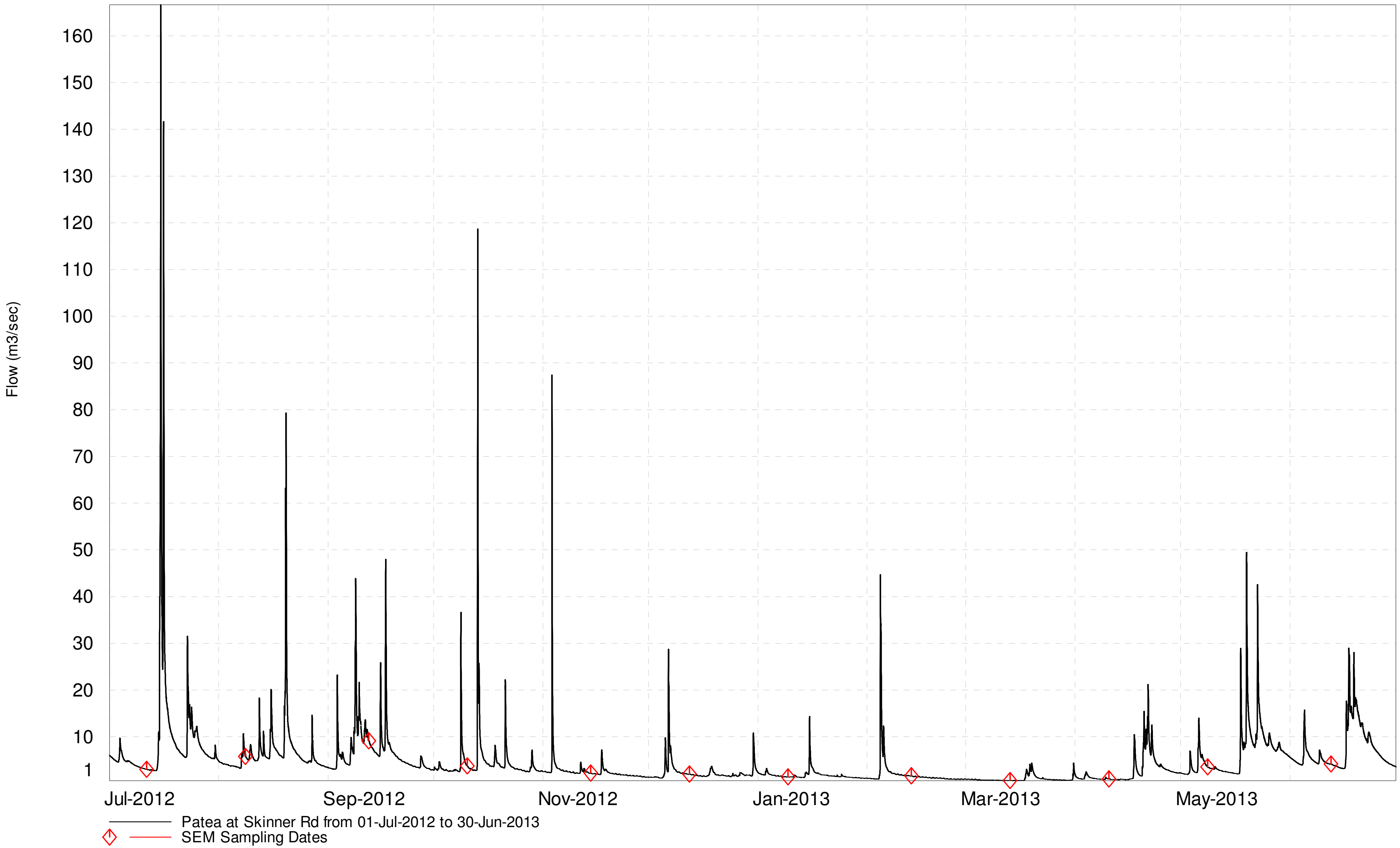


Figure 4 Flow in the Patea River at Skinner Road from July 2012 to June 2013

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 2012-2013

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	25.10.12	0815-0945	2.00	Clear, fine.	Calm	12	13.8	Turbid, pale brown; surface ripple; some debris	0.70	0.70	39
	21.02.13	0900-1000	2.37	Clear, fine.	Calm	19	23.1	Clear, brown-green; surface flat; no debris	3.28	2.68	37
	20.03.13	0845-0940	2.16	Clear, fine.	Mod.SE	17.5	20.7	Clear, dark green; surface slight chop; no debris	4.40	2.95	38
	18.06.13	1120-1155	N/R	Overcast, showers	Light N	13	11.1	Discoloured, dark grey-brown; surface ripple; some debris	3.15	2.70	37
L3	25.10.12	1020-1125	-	Clear, fine.	Mod. W	15.5	14.4	Discoloured, dark grey-green; surface ripple; no debris	2.70	2.13	37
	21.02.13	1035-1120	-	Partly cloudy, fine.	Light SE	23	23.0	Clear, dark green; surface light chop; no debris	3.30	2.75	40
	20.03.13	1045-1150	-	Clear, fine.	SE	19.5	21.0	Clear dark green; surface shop; no debris	3.75	N/R	46
	18.06.13	1010-1050	-	Overcast, showers	Calm	12	11.3	Discoloured, grey; surface flat; some debris	3.14	2.87	44

[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 2012

Location	Parameter	Unit	Minimum	Maximum	Median	N
L2 surface	Temperature	°C	9.4	23.9	16.9	87
L3 surface	Temperature	°C	9.5	24.6	17.5	87

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 2012-2013 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 (°C) of surface and bottom waters at each Lake Rotorangi site (October 2012 to June 2013)

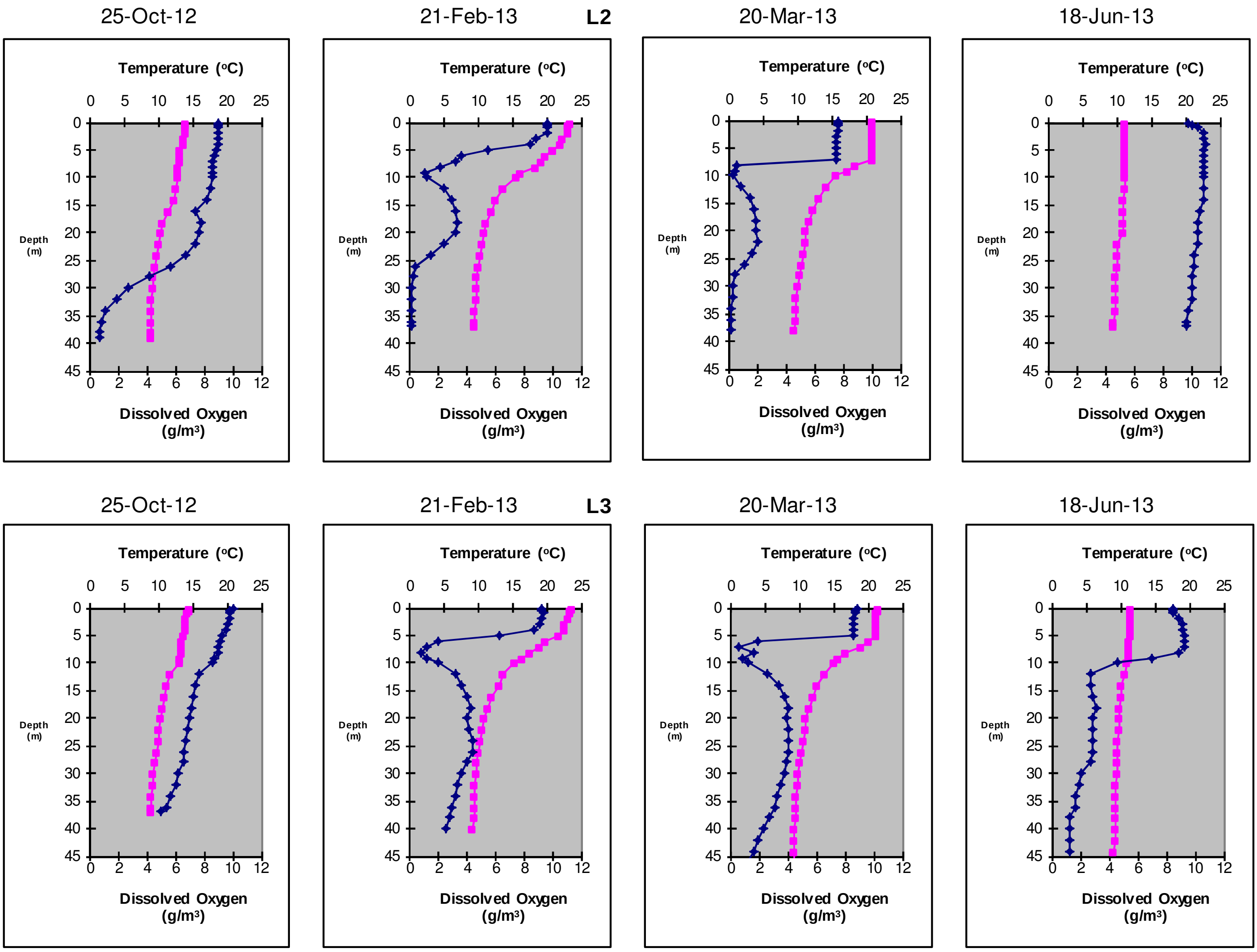
Sites	L2		L3	
Date	**Surface**	**Bottom**	**Surface**	**Bottom**
October 2012	13.8 (14.6)	8.9 (8.9)	14.4 (14.7)	8.9 (8.6)
February 2013	23.1 (21.7)	9.3 (9.7)	23.0 (22.1)	9.1 (9.4)
March 2013	20.7 (19.4)	9.4 (9.9)	21.0 (19.7)	8.9 (9.6)
June 2013	11.1 (11.2)	9.3 (9.3)	11.3 (11.3)	8.8 (9.4)

Note: *( ) = average monthly temperature for period 1984 to mid-2012*

All surface water temperatures at both sites were within past ranges measured at these sites (Table 4) and in the lake were within 1.5˚C of past monthly average temperatures at the time of all surveys. Bottom water temperatures at both sites were lower than surface water temperatures by about 2°C (winter) to 14°C (late summer) but within 0˚C to 0.7˚C of corresponding monthly average temperatures throughout the year. These two sites' bottom water temperatures (8.8°C to 9.4°C) showed a very narrow range (0.6°C) due to minimal mixing through the year, while their surface water temperature ranges were much wider (12.0°C [L2] to 11.7°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 2012 survey (Figure 5) while both summer-autumn surveys illustrated well-established thermal stratification at these mid and lower lake sites. The location of the thermocline was approximately 5 to 7 metres below the lake surface at both sites. The occurrence of many significant freshes between mid May and the winter June 2013 survey, and cooling of epilimnetic waters, contributed to the complete destruction of temperature stratification at these sites by the time of the June 2013 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.



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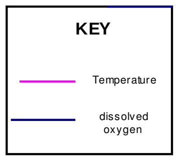


Figure 5 Temperature (˚C) and dissolved oxygen (g/m^3) profiles for site L2 and L3

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 2012

Location	Parameter	Unit	Minimum	Maximum	Median	N
L2 surface	Dissolved oxygen	g/m^3	6.8	11.1	8.8	87
	Dissolved oxygen saturation	%	68	116	92	87
L3 surface	Dissolved oxygen	g/m^3	3.6	10.7	8.8	87
	Dissolved oxygen saturation	%	34	116	94	87

Table 7 Temporal changes in percentage dissolved oxygen saturation in surface and bottom waters at each Lake Rotorangi site (October 2012 to June 2013)

Sites	L2		L3	
Date	Surface	Bottom	Surface	Bottom
October 2012	88 (93)	5 (29)	99 (96)	43 (34)
February 2013	112 (95)	9 (2)	110 (100)	22 (7)
March 2013	84 (92)	0 (5)	97 (93)	10 (7)
June 2013	90 (80)	85 (53)	78 (63)	10 (12)

Note: ( ) = average monthly saturation for period 1984 to mid-2012

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 16% of total saturation with the exception of the winter, partial overturn level which fell to 78% saturation at site L3. The level was also slightly below the saturation normally found at the time of the autumn survey at site L2. Partial mixing of relatively highly saturated surface waters with the poorer quality hypolimnetic waters was recorded at site L3 by the mid winter monitoring in June 2013.

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 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 2013 surveys at the mid lake site (L2) while the lower lake site L3 did not record total depletion at these times but approached total depletion (1 g/m^3) 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 to 28 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 eighteen of the previous nineteen years. Dissolved oxygen levels were below 2 g/m^3 in the lower lake waters of site L3 at the times of the autumn and winter surveys beyond 40 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 9.5 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 affected calculations for the 2011-2012 period, particularly at site L2

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	-38.9	46.6
February to March 1991	4.7	17.0
January to February 1992	5.7	14.6
February to March 1993	-11.8	9.0
January to February 1994	N/A	17.4
January to February 1995	27.8	46.7
February to March 1996	9.5	49.3
February to March 1997	N/A	31.6
February to March 1998	-0.7	13.2
February to March 1999	-6.4	27.2
February to March 2000	5.4	5.7
February to March 2001	-1.1	30.2
February to March 2002	1.5	17.8
February to March 2003	N/A	-0.8
February to March 2004	N/A	N/A
February to March 2005	20.6	58.3
February to March 2006	20.3	19.3
February to March 2007	5.9	4.3
February to March 2008	-6.7	16.6
February to March 2009	-9.3	29.7
February to March 2010	-22.2	-16.4
February to March 2011	9.2	38.0
February to March 2012	-5.3	6.4
Average	0.4	21.9
Standardised at:	10.2˚C	9.7˚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; and 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 2012

Location	Parameter	Unit	Minimum	Maximum	Median	N
L2 Surface	Secchi disc transparency	m	0.09	5.23	2.55	87
	Black disc transparency	m	0.09	4.50	2.00	79
	Turbidity	NTU	0.4	80	2.1	72
	Suspended solids	NTU	<2	83	2	80
	Conductivity @ 20°C	g/m^3	5.4	15.0	10.8	67
L2 Epilimnion	Turbidity	mS/m	0.6	90	2.2	77
	Suspended solids	g/m^3	<2	81	2	84
	Conductivity @ 20°C	mS/m	5.3	14.5	11.0	81
L2 Hypolimnion	Turbidity	NTU	1.6	230	5.0	80
	Suspended solids	g/m^3	<2	310	3	85
	Conductivity @ 20°C	mS/m	7.8	13.5	10.7	83
L3 Surface	Secchi disc transparency	m	0.26	7.00	3.10	87
	Black disc transparency	m	0.23	5.25	2.70	75
	Turbidity	NTU	0.5	30	1.4	74
	Suspended solids	g/m^3	<2	25	2	81
	Conductivity @ 20°C	mS/m	6.2	15.2	10.6	70
L3 Epilimnion	Turbidity	NTU	0.5	31	1.7	77
	Suspended solids	g/m^3	<2	26	2	85
	Conductivity @ 20°C	mS/m	6.2	15.0	10.7	81
L3 Hypolimnion	Turbidity	NTU	0.8	65	2.9	79
	Suspended solids	g/m^3	<2	89	2	87
	Conductivity @ 20°C	mS/m	6.2	12.4	10.3	83

Data recorded from each site during the 2012-2013 year (Table 10) were within ranges of previous results, with the secchi disc transparencies at both sites worse than median values on one occasion and suspended solids and turbidities above median values on only the one occasion at site L2 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 2012-2013 period

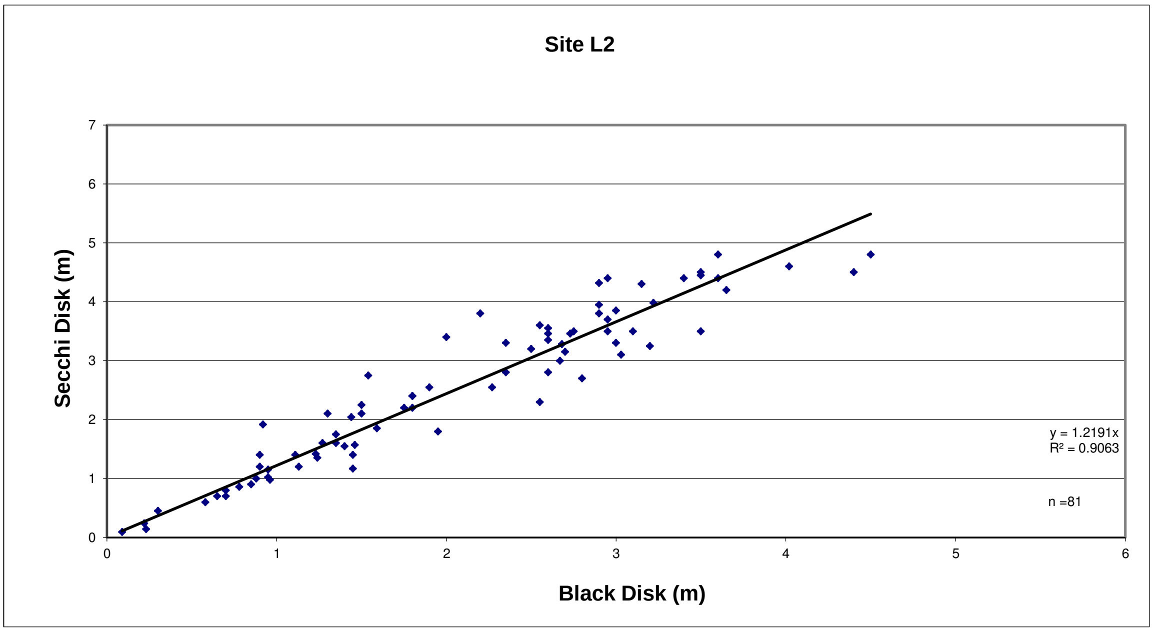
	Sites		L2			L3		
Date	**Parameter**	**Unit**	**S**	**E**	**H**	**S**	**E**	**H**
25.10.12	Secchi disc	m	0.70	-	-	2.70		-
	Turbidity	NTU	9.6	9.3	4.1	1.3	1.4	1.4
	Suspended solids	g/m³	7	7	3	<2	<2	<2
	Conductivity @ 20°C	mS/m	7.9	7.9	10.5	10.6	10.4	10.2
21.02.13	Secchi disc	m	3.28	-	-	3.30	-	-
	Turbidity	NTU	0.7	0.9	1.9	1.0	1.4	0.7
	Suspended solids	g/m³	<2	<2	<2	<2	<2	<2
	Conductivity @ 20°C	mS/m	12.6	12.4	10.7	11.2	11.1	10.1
20.03.13	Secchi disc	m	4.40	-	-	3.75	-	-
	Turbidity	NTU	0.8	1.2	15	1.1	1.0	77
	Suspended solids	g/m³	<2	<2	15	<2	<2	92
	Conductivity @ 20°C	mS/m	12.8	12.8	11.1	12.0	11.9	10.2
18.06.13	Secchi disc	m	3.15	-	-	3.14	-	-
	Turbidity	NTU	1.3	1.6	4.2	1.5	1.7	1.5
	Suspended solids	g/m³	<2	<2	2	<2	<2	<2
	Conductivity @ 20°C	mS/m	10.8	10.9	11.0	10.5	10.6	10.2
Range	Secchi disc	m	0.70-4.40	-	-	2.70-3.75	-	-
	Turbidity	NTU	0.7-9.6	0.9-9.3	1.9-15	1.0-1.5	1.0-1.7	0.7-77
	Suspended solids	g/m³	<2-7	<2-7	<2-15	<2	<2	<2-92
	Conductivity @ 20°C	mS/m	7.9-12.8	7.9-12.8	10.5-11.1	10.5-12.0	10.4-11.9	10.1-10.2

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

The impacts of relatively recent significant freshes resulted in particularly poor secchi disc clarity at site L2 and to a lesser degree at site L3 surface waters in spring (Table 10) with elevated turbidity and suspended solids levels through the water column at site L2.

A wider range of secchi disc transparency levels was recorded at site L2 (0.70 to 4.40 metres) than site L3 (2.70 to 3.75 metres) during the monitoring year. Impacts of river freshes upon lake clarity through the water column at site L2 were most marked in October 2013 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.



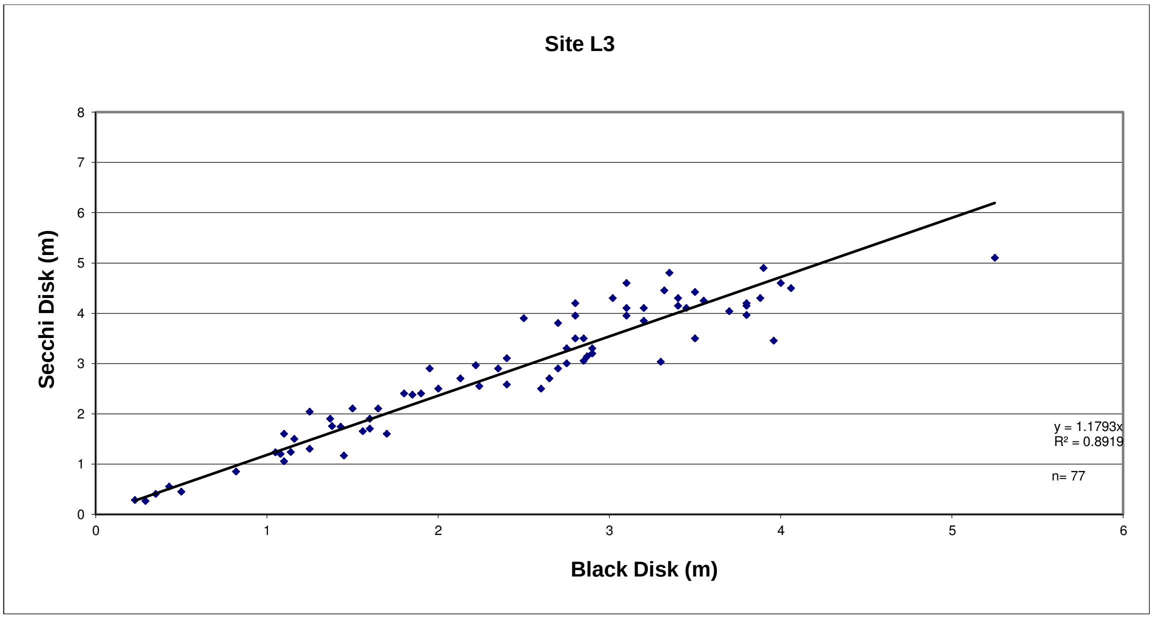


Figure 6 Relationship between secchi and black disc transparency at each sampling site

These trends have continued to be recorded during the most recent monitoring period under a moderate range of clarities. During the 2012-2013 monitoring period, black disc transparency ranges recorded at site L2 (0.70 to 2.95 metres) were wider than at site L3 (2.13 to 2.85 metres) 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 2012

Location	Parameter	Unit	Minimum	Maximum	Median	Mean	N
L2 photic zone	Chlorophyll-a	mg/m^3	<1.0	13.9	2.6	3.1	86
L3 photic zone	Chlorophyll-a	mg/m^3	<1.0	13.4	2.1	3.0	86

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 (1984-2012)	Result 2012-13	Mean (1984-2012)	Result 2012-13
October 2012	3.6	1.4	3.7	5.3
February 2013	3.4	4.9	2.8	4.2
March 2013	3.7	7.8	3.9	5.8
June 2013	1.7	1.9	1.5	2.4
Range: 2012-2013	-	1.4-7.8	-	2.4-5.8
Range: 1984-2012	-	<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 2012)

	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
2012	4	2.9	1.4-5.0	4	3.8	1.4-5.8

All chlorophyll-a concentrations measured at the two sites over the 2012-2013 period were within past ranges (Table 11) found by surveys since 1990.

Concentrations were higher than historical median monthly values at site L2 on all but the spring survey occasion and on all occasions at site L3.

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 autumn when concentrations were 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 7.8 mg/m^3 was measured at lake site L2 during the autumn period and this was 2.0 mg/m^3 higher than the concentration found at site L3 earlier in autumn (coincidental with a pH of 7.7 to 7.9 units in the surface water).

Mean 2012 values at both sites were typical of ranges at each site for the sampling period from 1994 to 2011 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 3.0 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 2012

Site	Parameter	Unit	Minimum	Maximum	Median	No. of samples
L2 Epilimnion	Dissolved reactive phosphorus	g/m^3P	<0.003	0.018	0.005	85
	Total phosphorus	g/m^3P	0.006	0.213	0.021	85
	Ammonia nitrogen	g/m^3N	<0.003	0.370	0.020	85
	Nitrite	g/m^3N	0.001	0.015	0.007	75
	Nitrate	g/m^3N	<0.01	0.99	0.31	77
	Total Kjeldahl nitrogen	g/m^3N	<0.01	1.20	0.28	82
	Total nitrogen	g/m^3N	0.21	1.65	0.63	81
	pH		6.9	8.6	7.5	77
L2 Hypolimnion	Dissolved reactive phosphorus	g/m^3P	<0.003	0.029	0.008	85
	Total phosphorus	g/m^3P	0.011	0.22	0.022	85
	Ammonia nitrogen	g/m^3N	<0.003	0.436	0.075	85
	Nitrite	g/m^3N	<0.001	0.022	0.009	75
	Nitrate	g/m^3N	0.02	0.93	0.48	79
	Total Kjeldahl nitrogen	g/m^3N	0.04	0.96	0.29	84
	Total nitrogen	g/m^3N	0.45	1.50	0.78	84
	pH		6.5	7.4	6.9	78
L3 Epilimnion	Dissolved reactive phosphorus	g/m^3P	<0.003	0.023	0.004	85
	Total phosphorus	g/m^3P	0.004	0.097	0.017	85
	Ammonia nitrogen	g/m^3N	<0.003	0.140	0.013	85
	Nitrite	g/m^3N	<0.001	0.020	0.005	75
	Nitrate	g/m^3N	<0.01	0.83	0.35	77
	Total Kjeldahl nitrogen	g/m^3N	<0.01	1.15	0.27	82
	Total nitrogen	g/m^3N	0.22	1.51	0.63	81
	pH		6.6	8.7	7.6	77
L3 Hypolimnion	Dissolved reactive phosphorus	g/m^3P	<0.003	0.026	0.006	85
	Total phosphorus	g/m^3P	0.006	0.134	0.017	85
	Ammonia nitrogen	g/m^3N	<0.003	0.170	0.007	85
	Nitrite	g/m^3N	<0.001	0.020	0.001	75
	Nitrate	g/m^3N	0.05	1.00	0.54	79
	Total Kjeldahl nitrogen	g/m^3N	<0.01	1.14	0.18	84
	Total nitrogen	g/m^3N	0.30	1.78	0.74	84
	pH		6.5	7.2	6.8	79

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

Parameter		Date			
	Unit	25 Oct 2012	21 Feb 2013	20 Mar 2013	18 Jun 2013
Sample Depth	m	4	3	3	4
Dissolved Reactive Phosphorus	g/m^3P	0.015	<0.003	0.004	0.013
Total Phosphorus	g/m^3P	0.045	0.029	0.040	0.028
Ammonia-N	g/m^3N	0.056	0.011	0.004	0.027
Nitrite	g/m^3N	0.012	0.001	0.001	0.012
Nitrate	g/m^3N	0.34	0.04	0.02	0.76
TKN	g/m^3N	0.19	0.27	0.23	0.18
Total nitrogen	g/m^3N	0.54	0.31	0.25	0.95
pH		7.3	8.0	7.8	7.3

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

Parameter		Date			
	Unit	25 Oct 2012	21 Feb 2013	20 Mar 2013	18 Jun 2013
Sample Depth	m	36	30	34	34
Dissolved Reactive Phosphorus	g/m^3P	0.019	0.009	0.013	0.012
Total Phosphorus	g/m^3P	0.032	0.022	0.051	0.028
Ammonia-N	g/m^3N	0.025	0.112	0.192	0.073
Nitrite	g/m^3N	0.013	0.008	0.008	0.016
Nitrate	g/m^3N	0.72	0.41	0.17	0.61
TKN	g/m^3N	0.08	0.19	0.42	0.22
Total nitrogen	g/m^3N	0.81	0.61	0.60	0.85
pH		6.7	6.8	6.9	7.2

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

Parameter		Date			
	Unit	25 Oct 2012	21 Feb 2013	20 Mar 2013	18 Jun 2013
Sample Depth	m	4	3	3	4
Dissolved Reactive Phosphorus	g/m^3P	0.005	<0.003	0.003	0.009
Total Phosphorus	g/m^3P	0.022	0.027	0.013	0.021
Ammonia-N	g/m^3N	0.007	0.007	0.015	0.003
Nitrite	g/m^3N	0.011	0.001	<0.001	0.014
Nitrate	g/m^3N	0.45	<0.01	<0.01	0.67
TKN	g/m^3N	0.08	0.34	0.23	0.25
Total nitrogen	g/m^3N	0.54	0.35	0.24	0.93
pH		7.6	8.2	7.9	7.1

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

Parameter	Unit	Date			
		25 Oct 2012	21 Feb 2013	20 Mar 2013	18 Jun 2013
Sample Depth	m	35	32	38	34
Dissolved Reactive Phosphorus	g/m^3P	0.010	0.006	0.008	0.004
Total Phosphorus	g/m^3P	0.025	0.012	0.196	0.015
Ammonia-N	g/m^3N	<0.003	<0.003	<0.003	<0.003
Nitrite	g/m^3N	0.004	<0.001	<0.001	<0.001
Nitrate	g/m^3N	0.68	0.66	0.61	0.52
TKN	g/m^3N	0.05	0.07	0.54	0.10
Total nitrogen	g/m^3N	0.73	0.73	1.15	0.62
pH		6.9	6.8	7.0	6.7

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. autumn, 2013). 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, mainly at site L2, but not to the same degree at site L3 where turbidities only varied over a relatively small range (< 1 NTU) in the 2012-2013 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 and autumn 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 (7.8 to 8.2), 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 (7.1 to 7.6) in spring 2012 and mid winter 2013 at mid and lower lake sites.

2.1.1.6.2 Hypolimnion

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 (6.7 to 7.2 units), often significantly lower (by up to 1.4 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 very similar (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 at site L2 in autumn 2013, 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. [Note: No autumn sampling was able to be undertaken in 2013 due to anchoring issues at both sites]. A summary of historical data is provided in Table 19.

Table 19 Statistical summary of nutrients and related data during late summer-autumn in the lower hypolimnion in relation to comparative hypolimnetic data at sites L2 and L3 from 1996 to June 2012

Site	Location			Lower hypolimnion (near bed)			Hypolimnion			
	Parameter	Unit	N	Minimum	Maximum	Median	N	Minimum	Maximum	Median
L2	Dissolved reactive phosphorus	g/m³P	33	<0.003	0.040	0.008	34	<0.003	0.017	0.008
	Total phosphorus	g/m³P	33	0.012	0.276	0.023	34	0.011	0.220	0.020
	Ammonia nitrogen	g/m³N	33	0.015	0.622	0.148	34	0.014	0.289	0.121
	Nitrate	g/m³N	28	<0.01	0.70	0.41	34	0.02	0.70	0.45
	Temperature	°C	33	8.1	14.3	9.4	34	8.1	14.4	9.5
	Turbidity	NTU	33	2.4	310	9.8	34	1.6	230	4.5
	Dissolved oxygen	g/m³	33	0	6.4	0	34	0	7.6	0
	pH		24	6.5	7.0	6.8	34	6.5	7.3	6.8
L3	Dissolved reactive phosphorus	g/m³P	32	<0.003	0.032	0.008	34	<0.003	0.024	0.006
	Total phosphorus	g/m³P	32	0.008	0.298	0.026	34	0.006	0.082	0.016
	Ammonia nitrogen	g/m³N	32	<0.003	0.111	0.015	34	<0.003	0.064	0.007
	Nitrate	g/m³N	28	0.12	0.69	0.54	34	0.17	0.78	0.59
	Temperature	°C	32	7.4	14.7	9.2	34	7.7	14.9	9.3
	Turbidity	NTU	31	1.0	140	13	34	0.9	65	2.0
	Dissolved oxygen	g/m³P	32	0	3.5	0.6	34	0	4.8	1.6
	pH		22	6.6	7.0	6.8	34	6.6	7.1	6.8

Historical median data (1996-2012) indicate that the general trend at both sites (L2 and L3) has been a small increase in ammoniacal nitrogen and very small decrease in nitrate N in the hypolimnetic anoxic zone near the sediment interface compared to the hypolimnetic water column. 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 2013 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 occasion (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 2012-2013 period

Site		L2		L3	
Parameter	**Unit**	**21 Feb 2013**	**20 Mar 2013**	**21 Feb 2013**	**20 Mar 2013**
Sample Depth	M	36	N/S	38	N/S
Dissolved Reactive Phosphorus	g/m^3P	0.011	-	0.005	-
Total Phosphorus	g/m^3P	0.022	-	0.012	-
Ammonia-N	g/m^3N	0.159	-	<0.003	-
Nitrate-N	g/m^3N	0.22	-	0.64	-
[Dissolved oxygen]	g/m^3	[0]	-	[2.8]	-
[Turbidity]	NTU	[5.2]	-	[0.7]	-
[pH]		[6.7]	-	[6.8]	-
[BOD_5]	g/m^3	[2.0]	-	[0.6]	-

[ ] = additional parameters N/S = not able to sample

During the summer stratification period anoxic conditions were present in the lower hypolimnion at site L2 but only approached low levels at site L3 in February 2013 (see Figure 5). Both sites showed no increases in dissolved reactive phosphorus 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 February 2013. An increase in ammonia nitrogen (of 0.047 g/m^3N) in February 2013 at site L2 was consistent with reducing conditions deep in the anoxic zone with a reduction in nitrate nitrogen concentration on this survey occasion.

Differences in nutrient species between the deeper hypolimnetic waters and waters higher in the hypolimnion were more marked at site L2 during late summer when complete anoxia was recorded. However all nutrient concentrations measured near the lake bed at sites L2 and L3 (Table 20) were within the range and near to, or below the median of historical data (Table 19) measured during summer-autumn anoxic and near anoxic conditions. Total phosphorus did not increase significantly on either occasion when turbidities indicated minimal change in fine suspended sediment in the water near the lakebed.

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 2012-2013 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 1990-2012 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-two year period, a more significant temporal increase in nitrate-N is consistent with a very slow rate of increase in trophic level (Burns, 2006 and Appendix II).

2.2 Biological monitoring

2.2.1 Methods

During the 2012-2013 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;

The macrophyte survey was performed in the previous year (April 2012), with both banks visually surveyed from a moving boat. The dominant species was recorded, with the presence of other species 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 2012, February 2013, and June 2013. 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.

The benthic macroinvertebrate samples were collected by Ekman dredge from the lakebed at sites L2 and L3 in conjunction with the survey of October 2012. These samples were passed 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 25 October 2012, 21 February, and 18 June 2013. 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 2012-2013 period

Date	25/10/2012	21/02/2013	18/06/2013
GREEN ALGAE			
Ultraplankton (unidentified))	P	P	
Chlorella-like unicells		P	
CYANOBACTERIA			
Oscillatoria/Planktothrix			
DIATOMS			
Nitzschia			
Synedra			P
CRYPTOPHYTES			
Cryptomonas			P
Total taxa number	1	2	2

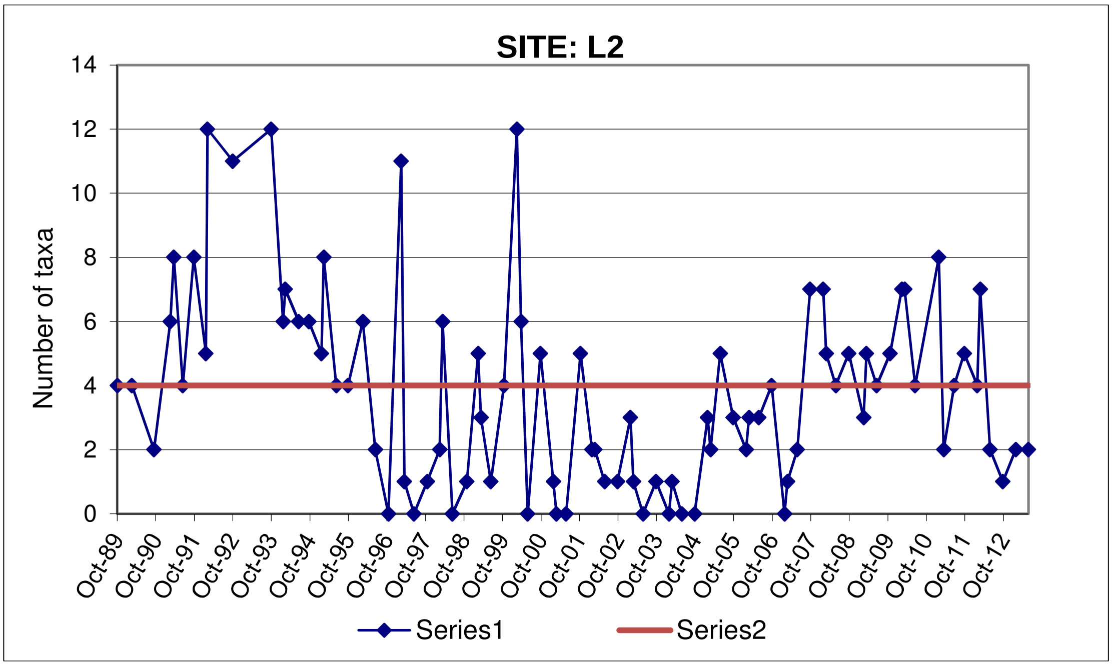


Figure 7 Number of phytoplankton taxa recorded at site L2 in Lake Rotorangi since monitoring began in 1989

Low numbers of taxa (1 to 2) were present at site L2 during the 2012-2013 monitoring period, with numbers below the historical median and average (4 taxa) on all occasions (Figure 7). Chlorophyll-a concentrations ranged over relatively low levels (1.4 to 1.9 mg/gm³ (Table 12)), when these phytoplankton communities comprised few taxa, none of which was abundant at this site.

2.2.2.1.2 Site L3

Low numbers of taxa were also found at L3 during the 2012-2013 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 twelve years. Three taxa were present on each of the three sampling occasions (Figure 8) coincident with chlorophyll-a concentrations of a relatively low range (2.4 to 5.3 mg/m³ (Table 12)).

Table 22 Phytoplankton found at site L3 in Lake Rotorangi in the 2012-2013 period

Date	25/10/2012	21/02/2013	18/06/2013
GREEN ALGAE			
Ultraplankton (unidentified)		A	P
Chlorella		P	
CYANOBACTERIA			P
unidentified	P		
DIATOMS			
Asterionella	P		
EUGLENCOIDS			
Trachelomonas		P	
CRYPTOPHYTES			
Cryptomonas	P	-	P
Total taxa number	3	3	3

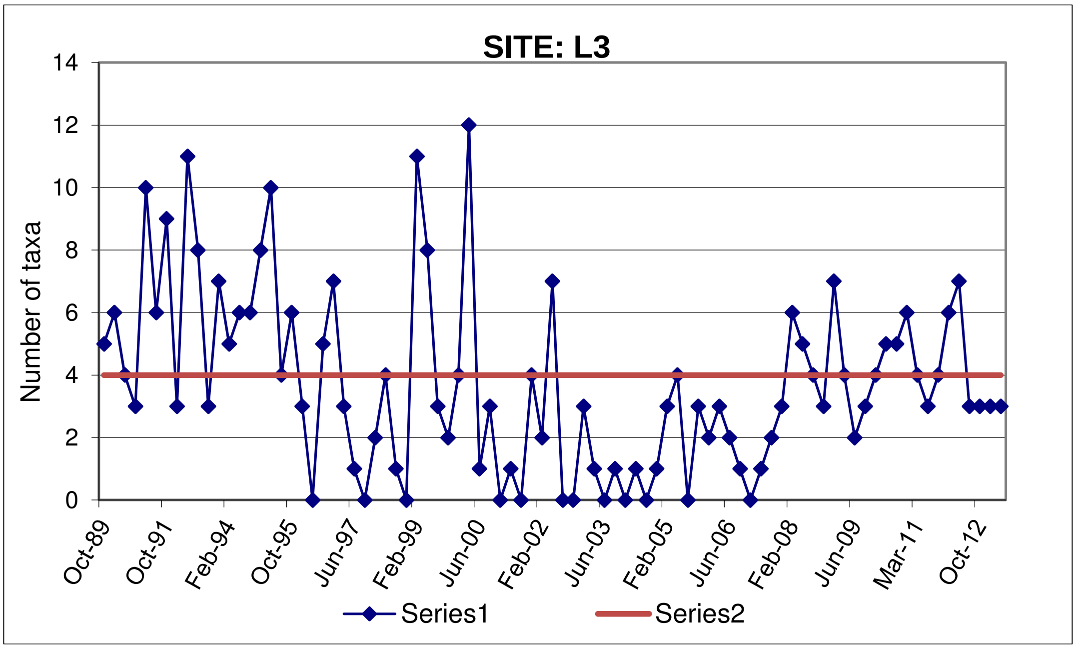


Figure 8 Number of taxa recorded at site L3 in Lake Rotorangi since monitoring began in 1989

No individual taxon was present on all three survey occasions (*Cryptomonas*) and only one taxon (unidentified green alga) was abundant at the time of any of the three surveys.

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, low taxonomic richnesses were found at all sites throughout the 2012-2013 monitoring year with only one algal taxon found in abundance. Taxa richnesses on all survey occasions were less than and 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 2012 survey, the faunal samples from the fine greyish-black muddy sediments at sites L2 and L3 were collected from depths of 39 and 37 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	**October 1992**		**June 1994**		**Sept 1994**		**October 1995**		**October 1996**		**October 1997**		**Nov 1998**		**October 1999**		**October 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																				
Orthocladiinae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tanypodinae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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**	**L2**	**L3**
Date	**October 2002**		**October 2003**		**October 2004**		**October 2005**		**October 2006**		**October 2007**		**October 2008**		**October 2009**		**October 2010**		**October 2011**		**October 2012**	
ANNELIDA																						
Oligochaeta	A	C	C	R	A	A	XA	R	A	A	A	A	A	A	C	A	C	C	A	A	VA	A
Branchiura	-	-	-	-	-	-	-	-	R	-	-	-	-	R	R	-	-	-	-	-	-	-
MOLLUSCA																						
Potamopyrgus	R	R	-	-	-	-	R	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-
Physa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CRUSTACEA																						
Copepoda	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cladocera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracoda	C	-	C	-	-	-	R	-	-	R	-	-	-	-	-	-	-	-	-	-	R	R
DIPTERA																						
Orthocladiinae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tanypodinae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R
Chironomus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	-	R
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	2	4

[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, 2012 and were abundant at site L3 and very abundant at site L2. Ostracod seed shrimps, found at site L3 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 but was not present at either site in October, 2012 at which time two other midge taxa were found at site L3 in very low numbers.

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

The most recent survey of the aquatic macrophytes in Lake Rotorangi was performed on 26 April 2012 of the previous monitoring year. 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). Results of that survey are presented in Figure 9 and 10 and discussed beneath.

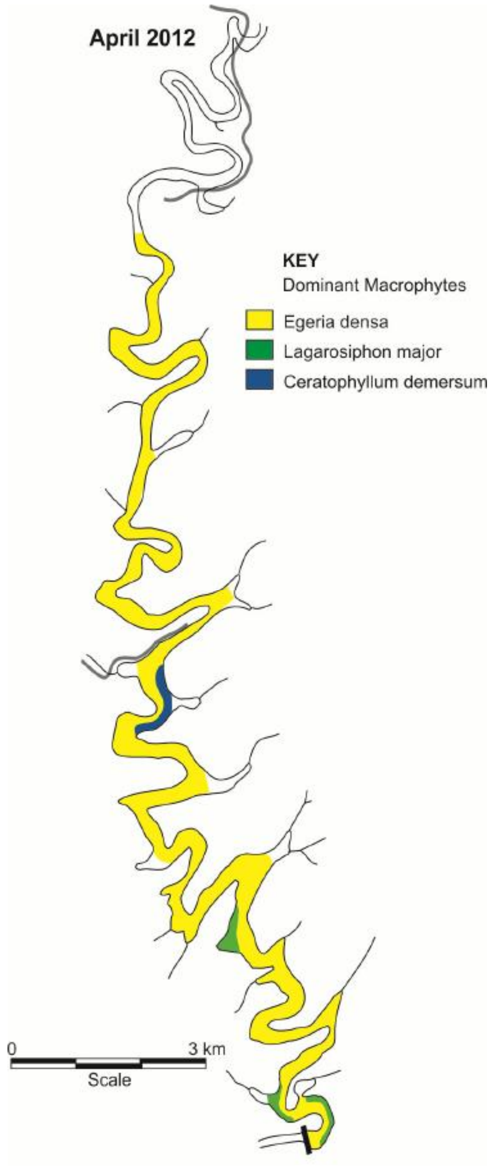


Figure 9 Dominant macrophytes recorded in Lake Rotorangi on 26 April 2012

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.

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'.

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[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.

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.

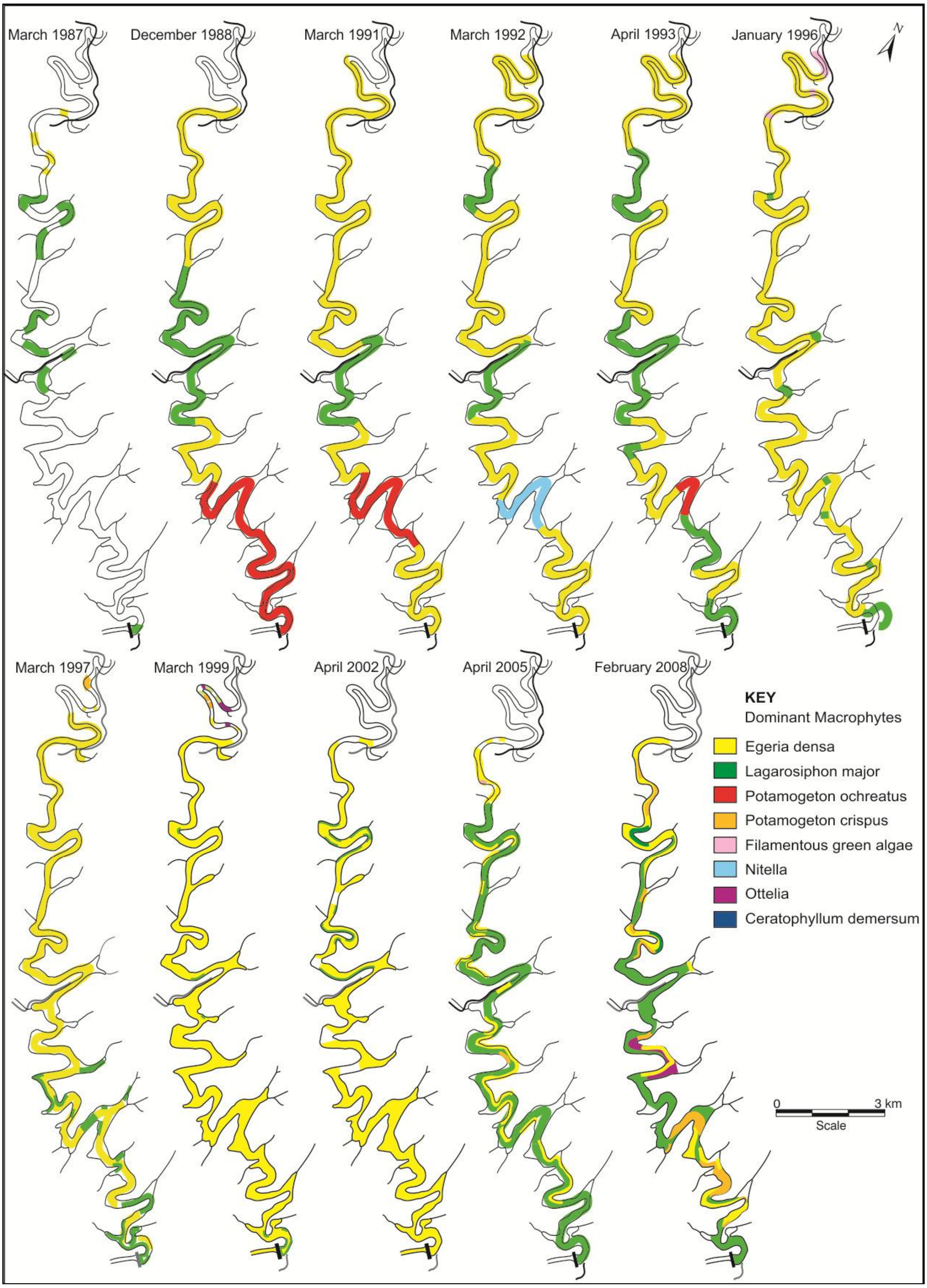

Figure 10 Dominant macrophytes in Lake Rotorangi from March 1987 to February 2008

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*** (NIWA photo)

[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 2012-2013 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 2013). Normal lake overturn was complete at site L2 but only partially complete at site L3 in mid-winter (June 2013). 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 and July 2013 from readings taken through the water column 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 2012 (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 (2012-2013) surveys were related to the recency of river freshes. Freshes prior to the spring (2012), survey in particular 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 22 year period 1990-2012 (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). 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 nitrate-nitrogen.

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 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 autumn at both the mid lake site and at the lower lake site.

The summer 2012 macrophyte survey (performed in the previous monitoring period) 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. These were updated during the 2012-2013 period.

A very sparse macroinvertebrate fauna, confined mainly to oligochaete (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 site L2 and three other taxa at site L3 all of which were found as rarities.

3.2 2011-2012 Report's recommendations

The recommendation contained in the 2011-2012 Annual Report based upon the monitoring programme results was:

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.

This recommendation (1) was implemented with the continuation of a State of the Environment monitoring programme to include the physicochemical and biological water quality monitoring. Once every three years this will be 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 2013-2014

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. No alterations are required to 2013-2014 programme

A recommendation to this effect is attached to this report.

4. Recommendation

The following recommendation is based on the results of the 2012-2013 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 (next in 2014-2015).

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 2012 to 30 June 2013

Source is R:\PROCESSING-FILE\WATER TAKES & DISCHARGES.hts
Synthetic Inflow (m3/sec) at Patea Dam
From 1-Jul-2012 00:00:00 to 30-Jun-2013 24:00:00
24 hour periods beginning at midnight each day.

Daily means Years 2012-2013 Synthetic Inflow(m3/sec) at Patea Dam

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
1	21.281	18.264	13.301	13.883	8.768	5.765	15.948	4.241	3.580	7.465	18.322	18.098	
2	18.436	15.139	12.445	19.466	8.149	6.390	10.439	4.203	3.543	5.533	11.280	16.373	
3	17.652	13.926	26.514	17.191	23.731	8.921	17.710	4.055	3.527	4.730	11.494	14.911	
4	31.489	13.085	52.756	13.571	16.471	7.074	16.059	15.557	3.439	7.257	10.498	14.595	
5	23.145	12.835	30.724	14.579	10.272	10.332	9.890	55.793	3.394	6.967	9.703	29.758	
6	18.645	12.331	21.693	13.094	8.275	24.935	7.895	22.948	3.373	4.694	18.620	20.231	
7	16.187	26.938	21.529	14.784	7.336	31.548	6.901	10.270	3.393	4.124	16.579	14.732	
8	14.349	43.618	48.097	18.448	6.759	23.397	6.182	7.721	3.384	3.996	11.989	13.067	
9	13.075	33.301	91.805	23.913	6.401	13.038	5.981	6.669	3.363	3.833	9.815	14.729	
10	12.082	27.487	83.866	23.589	6.106	9.546	5.929	6.132	3.305	3.859	9.508	16.368	
11	11.420	20.658	73.416	17.316	7.384	8.401	7.082	5.838	3.268	3.632	9.508	13.644	
12	10.994	27.975	62.696	13.977	13.356	7.659	7.444	5.596	3.226	3.533	8.782	12.445	
13	11.656	39.084	42.270	66.283	17.871	7.151	5.973	5.419	3.206	3.553	7.723	11.629	
14	12.721	43.189	30.201	101.701	12.834	6.634	6.675	5.131	3.186	3.693	7.344	11.532	
15	76.576	37.139	26.970	39.703	9.947	6.215	12.720	4.881	3.202	3.575	7.141	10.691	
16	264.442	43.597	29.644	24.141	9.554	5.921	17.384	4.705	3.251	3.748	6.874	11.851	
17	175.418	39.545	45.682	19.048	13.414	5.714	11.778	4.642	3.507	9.018	8.197	62.465	
18	57.533	28.862	38.521	62.076	24.027	7.703	10.391	4.425	6.203	26.283	32.379	194.172	
19	35.752	35.461	25.580	49.383	16.574	10.064	8.568	4.210	25.826	11.196	66.394	122.153	
20	27.156	144.420	22.531	21.207	11.843	8.786	6.772	4.153	23.888	44.988	84.817	107.521	
21	22.880	105.091	19.780	28.309	9.930	6.636	6.427	4.065	11.591	57.081	34.715	109.340	
22	20.221	46.696	17.589	36.770	8.755	6.388	6.144	3.994	6.386	33.631	40.568	69.730	
23	40.689	31.063	16.228	21.835	8.015	6.205	5.671	3.819	4.977	34.232	55.916	46.898	
24	38.408	24.722	15.054	16.125	7.693	5.855	5.494	3.676	4.479	26.091	41.958	33.624	
25	58.207	21.082	14.073	13.392	7.275	9.754	5.401	3.581	4.183	21.954	27.682	26.185	
26	33.475	19.168	13.267	11.756	6.947	8.901	5.065	3.518	4.020	26.253	48.243	22.406	
27	24.917	21.991	14.254	10.561	6.787	20.277	4.795	3.529	3.975	15.704	36.983	19.272	
28	21.215	22.578	12.888	14.103	6.406	14.202	4.606	3.571	3.857	11.916	29.747	16.936	
29	18.917	19.585	12.105	19.807	5.979	35.468	4.496		3.807	9.800	40.770	14.894	
30	17.809	15.985	11.391	13.401	5.780	22.146	4.370		3.796	9.006	26.461	13.826	
31	21.816	14.458		9.791		29.335	4.308		5.297		21.293		
Min	10.994	12.331	11.391	9.791	5.780	5.714	4.308	3.518	3.186	3.533	6.874	10.691	3.186
Mean	38.341	32.880	31.562	25.265	10.421	12.270	8.210	7.727	5.465	13.712	24.881	36.803	20.707
Max	264.442	144.420	91.805	101.701	24.027	35.468	17.710	55.793	25.826	57.081	84.817	194.172	264.442

Source is R:\ARCHIVES\HYDRO-ARCHIVES.HTS
Flow (m3/sec) at Mangaehu at Bridge
From 1-Jul-2012 00:00:00 to 30-Jun-2013 24:00:00
24 hour periods beginning at midnight each day.

Daily means Years 2012-2013 Flow(m3/sec) at Mangaehu at Bridge

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
1	11.738	9.398	6.984	7.417	5.268	2.988	10.048	2.145	1.812	4.224	11.435	8.729	
2	10.071	7.337	6.525	11.224	4.983	3.421	6.182	2.153	1.799	3.137	6.464	7.953	
3	9.479	6.615	13.368	9.764	7.223	5.191	11.433	2.095	1.794	2.468	5.444	7.311	
4	17.637	6.240	34.657	7.307	9.740	4.086	10.373	3.699	1.763	3.680	5.143	6.726	
5	12.900	6.145	18.729	8.174	6.155	4.556	5.941	32.342	1.781	3.975	4.571	13.712	
6	9.538	5.959	12.950	7.054	4.991	11.506	4.696	13.358	1.776	2.497	6.979	9.659	
7	8.053	16.137	10.790	8.216	4.490	18.644	4.060	5.203	1.785	2.177	7.795	6.575	
8	7.061	26.711	24.280	6.923	4.206	14.668	3.638	3.739	1.775	2.130	5.628	5.850	
9	6.415	20.090	56.439	12.281	4.063	7.250	3.527	3.139	1.763	1.955	4.437	6.109	
10	5.955	14.903	53.525	14.129	3.981	5.024	3.484	2.861	1.724	1.963	4.260	7.807	
11	5.660	10.949	46.746	9.859	4.681	4.366	4.181	2.715	1.700	1.916	4.402	6.311	
12	5.486	13.735	39.343	7.556	8.513	3.938	4.633	2.612	1.674	1.857	4.121	5.609	
13	5.981	23.313	25.870	28.593	10.848	3.676	3.621	2.535	1.654	1.879	3.513	5.246	
14	5.830	27.209	17.621	67.067	7.181	3.415	3.728	2.426	1.639	1.936	3.350	5.405	
15	11.747	20.344	14.289	25.132	5.285	3.201	5.909	2.291	1.646	1.905	3.303	5.035	
16	153.737	24.266	14.237	14.027	5.069	3.054	10.392	2.218	1.658	1.968	3.217	5.004	
17	113.457	23.590	19.992	9.250	6.774	2.932	7.018	2.205	1.743	3.812	3.308	32.041	
18	33.342	16.315	22.705	39.754	15.010	3.485	6.241	2.142	2.558	15.730	13.612	126.652	
19	19.228	18.018	13.745	32.871	9.628	5.289	5.123	2.079	15.821	6.552	33.700	72.156	
20	14.016	84.132	11.689	12.730	6.414	4.944	3.946	2.053	15.283	26.799	49.720	65.370	
21	11.491	69.062	10.101	14.351	5.273	3.524	3.590	2.013	6.786	31.154	17.778	68.516	
22	9.948	28.611	8.814	24.280	4.630	3.399	3.163	1.998	3.430	17.307	17.234	41.836	
23	16.170	18.133	8.077	13.571	4.205	3.345	2.865	1.927	2.549	19.886	27.836	25.525	
24	18.437	14.091	7.473	9.444	4.018	3.115	2.717	1.865	2.259	15.494	21.634	17.512	
25	34.186	11.772	6.989	7.527	3.799	5.787	2.673	1.806	2.088	12.766	13.148	13.182	
26	17.384	10.373	6.596	6.570	3.614	5.221	2.542	1.765	1.985	16.233	27.239	11.218	
27	12.383	10.640	6.345	5.954	3.509	13.607	2.408	1.768	1.963	8.943	20.428	9.646	
28	10.254	12.941	6.165	8.050	3.288	8.988	2.311	1.798	1.893	6.495	15.331	8.462	
29	8.992	11.194	6.009	12.289	3.063	25.459	2.243		1.871	5.144	23.221	7.391	
30	8.318	8.637	5.722	8.278	2.988	13.360	2.197		1.853	4.675	13.681	6.913	
31	11.175	7.652		5.920		19.427	2.179		2.001		10.506		
Min	5.486	5.959	5.722	5.920	2.988	2.932	2.179	1.765	1.639	1.857	3.217	5.004	1.639
Mean	20.196	18.855	17.893	14.696	5.763	7.125	4.744	3.891	2.962	7.689	12.659	20.649	11.471
Max	153.737	84.132	56.439	67.067	15.010	25.459	11.433	32.342	15.821	31.154	49.720	126.652	153.737

Source is R:\ARCHIVES\HYDRO-ARCHIVES.HTS
Flow (m3/sec) at Patea at Skinner Rd
From 1-Jul-2012 00:00:00 to 30-Jun-2013 24:00:00
24 hour periods beginning at midnight each day.

Daily means Years 2012-2013 Flow(m3/sec) at Patea at Skinner Rd

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
1	5.697	4.529	3.294	3.101	2.525	1.333	2.137	1.094	0.902	1.368	2.132	5.298	
2	5.031	4.191	3.121	3.638	2.398	1.353	1.878	1.039	0.868	1.010	1.989	4.723	
3	5.350	4.006	8.489	3.106	14.443	1.335	2.505	0.966	0.861	1.207	3.633	4.221	
4	6.734	3.772	5.906	2.824	4.476	1.206	1.942	10.803	0.795	1.918	2.899	5.188	
5	4.865	3.669	5.465	2.667	3.152	3.778	1.746	9.543	0.748	1.235	3.302	9.341	
6	4.739	3.460	4.125	2.721	2.808	8.482	1.616	3.641	0.740	1.074	7.983	5.951	
7	4.254	5.128	6.689	2.800	2.611	5.634	1.546	2.465	0.734	0.974	5.030	4.972	
8	3.811	6.755	16.591	8.175	2.462	2.996	1.432	2.134	0.725	0.917	3.669	4.403	
9	3.507	5.677	14.629	6.184	2.350	2.414	1.402	1.963	0.706	1.004	3.258	5.703	
10	3.240	6.379	11.290	3.785	2.226	2.214	1.413	1.837	0.685	1.001	3.233	4.893	
11	3.041	4.926	10.876	3.139	2.811	2.075	1.630	1.763	0.668	0.858	3.014	4.342	
12	2.899	8.599	9.708	2.857	2.842	1.971	1.363	1.679	0.650	0.848	2.716	4.158	
13	2.834	7.176	7.679	26.580	2.441	1.863	1.307	1.605	0.645	0.843	2.539	3.878	
14	4.420	5.712	6.627	8.103	2.190	1.746	1.902	1.492	0.636	0.890	2.407	3.586	
15	56.370	9.524	8.632	4.936	2.081	1.633	4.776	1.433	0.629	0.825	2.279	3.294	
16	48.803	9.439	9.377	4.074	2.012	1.566	3.359	1.367	0.651	0.913	2.147	5.161	
17	15.771	6.980	18.451	3.683	3.526	1.577	2.278	1.324	0.853	3.849	4.556	17.169	
18	10.975	5.992	8.184	5.554	3.052	2.815	2.038	1.259	2.224	3.558	11.334	15.147	
19	8.734	13.174	6.645	4.133	2.462	2.460	1.837	1.204	3.344	1.722	18.630	18.885	
20	7.237	24.824	5.767	3.455	2.164	1.821	1.761	1.182	1.970	7.621	12.861	14.321	
21	6.315	9.006	5.101	8.427	2.054	1.742	1.630	1.143	1.211	12.071	8.629	12.189	
22	5.750	7.203	4.632	4.212	1.965	1.705	1.578	1.092	1.052	8.395	15.967	9.582	
23	17.456	6.119	4.279	3.430	1.846	1.599	1.523	0.999	0.939	5.595	14.778	10.067	
24	12.215	5.247	3.945	3.123	1.792	1.611	1.562	0.946	0.864	3.918	10.306	8.100	
25	11.152	4.661	3.657	2.977	1.699	1.720	1.505	0.921	0.811	3.731	8.427	6.948	
26	8.792	4.623	3.442	2.766	1.647	1.700	1.373	0.922	0.790	3.134	9.340	6.019	
27	7.124	6.992	4.740	2.580	1.612	2.121	1.291	0.921	0.763	2.824	7.356	5.189	
28	6.215	4.836	3.647	3.701	1.535	1.778	1.240	0.919	0.742	2.531	7.729	4.578	
29	5.623	4.117	3.185	3.714	1.443	1.761	1.221		0.711	2.341	7.343	4.109	
30	5.514	3.804	2.926	2.736	1.362	4.276	1.159		0.719	2.243	6.534	3.746	
31	5.716	3.520		2.649		3.297	1.123		1.970		5.925		
Min	2.834	3.460	2.926	2.580	1.362	1.206	1.123	0.919	0.629	0.825	1.989	3.294	0.629
Mean	9.683	6.582	7.037	4.704	2.733	2.374	1.777	2.059	0.987	2.681	6.514	7.172	4.541
Max	56.370	24.824	18.451	26.580	14.443	8.482	4.776	10.803	3.344	12.071	18.630	18.885	56.370

Appendix II

TRC Lake Rotorangi water quality trend analysis 1990-2012

Memorandum

To CR Fowles, Scientific Officer
From Fiza Hafiz, Scientific Officer SEM
Document #1257894
Date 3 October 2013

Lake Rotorangi trend analysis January 1990 to December 2012

Introduction

A trend analysis of Lake Rotorangi monitoring data from 1990 to 2012 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 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 2.3% per year (or 7.62 $mgN/m^3/year$) and chlorophyll *a* is increasing by 1.7% per year (0.05 $mgN/m^3/year$). The trend for total suspended solid however is showing a decline by - 4.0% per year (0.16 $mg/m^3/year$). Although it showed a small decline, the total suspended solid have managed to decrease in the last couple of years. Figure 1, Figure 2 and Figure 3 present the significant trends graphically for the combined sites data. Trends are presented graphically for all parameters for combined sites (Appendix 2) and individual sites (Appendices 3 and 4).

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 slightly lower magnitude (1.04%/year). Unlike the previous years, the long-term trend for dissolved reactive phosphorus has not shown any significant change at all the lake sites monitored and the in the upstream catchment of the Patea River.

Table 1 Trends in water quality parameters in Lake Rotorangi for monitoring conducted from 1990 to 2012

Parameter	L2	L3	L2 & L3
Chlorophyll a	😐	😐	🙁
DO	😐	😐	😐
EC	😐	😐	😐
Secchi Depth	😐	😐	😐
TSS	😐	😐	🙁
Temperature	😐	😐	😐
DRP	😐	😐	😐
NH_4	😐	😐	😐
NO_3	☹	☹	☹
TN	😐	😐	😐
TP	😐	😐	😐
HVOD	😐	😐	😐
TLI	😐	😐	😐

Key:

😃 statistically very significant **improvement** P<0.01 (1%)

🙂 statistically significant **improvement** P<0.05 (1%)

😐 **no statistically significant change**

🙁 statistically significant **deterioration** P<0.05 (5%)

☹ 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)

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 1990-2012 period is 4.16 (±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 indicate that the lake is in a mesotrophic state, and the secchi depth and 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 4.25 (possibly as a result of this site's proximity to the upper catchment) due to the higher total nitrogen level and lower secchi depth (refer to Appendices 2 and 3). The TLI for chlorophyll *a* and total phosphorous indicated a mesotrophic state. The L3 TLI (3.84) indicated mesotrophic conditions in the 2012 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 1990-2012 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 2012 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 1990-2012 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

Table 3 *p* and R values for trend analysis of 1990-2012 data at sites L2 and L3 in Lake Rotorangi

Parameter	L2		L3		L2 & L3	
	p-value	R	*p*-value	R	*p*-value	R
Chlorophyll a	0.08	0.19	0.32	0.11	0.05	0.15
DO	0.06	-0.20	0.45	-0.08	0.12	-0.12
EC	0.08	0.17	0.35	0.09	0.06	0.12
Secchi Depth	0.49	0.08	0.27	-0.12	0.70	-0.03
TSS	0.12	-0.14	0.06	-0.17	0.04	-0.13
Temperature	0.27	-0.12	0.62	-0.05	0.25	-0.09
DRP	0.29	0.11	0.99	-0.002	0.44	0.06
NH_4	0.83	0.02	0.83	-0.02	0.90	0.01
NO_3	0.0057	0.28	0.0014	0.33	0.00003	0.298
TN	0.55	0.06	0.88	-0.02	0.74	0.02
TP	0.90	-0.01	0.93	-0.01	0.88	-0.01
HVOD	0.76	0.08	0.26	-0.25	0.48	-0.16
TLI	0.31	0.11	0.17	0.17	0.15	0.15

Values in orange = significant trend at $p<0.05$, values in red = significant trend at $p<0.01$

References

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

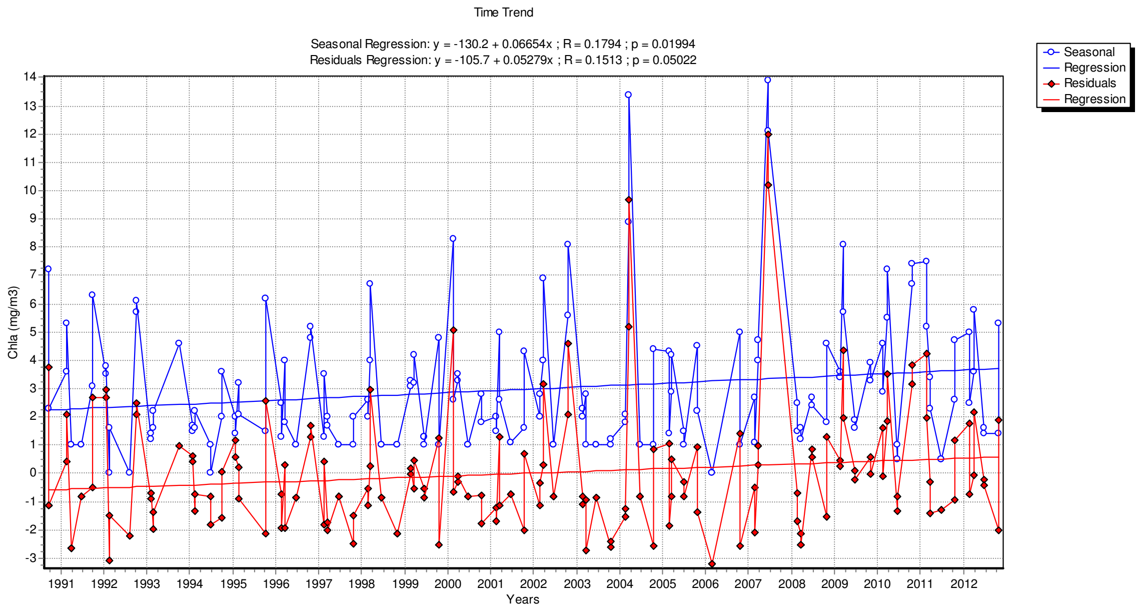
Burns N.M., Bowman E and Bryers G., 2000: Protocol for monitoring the trophic levels of New Zealand Lakes and Reservoirs. New Zealand Ministry for the Environment, Wellington, NZ. 138p.

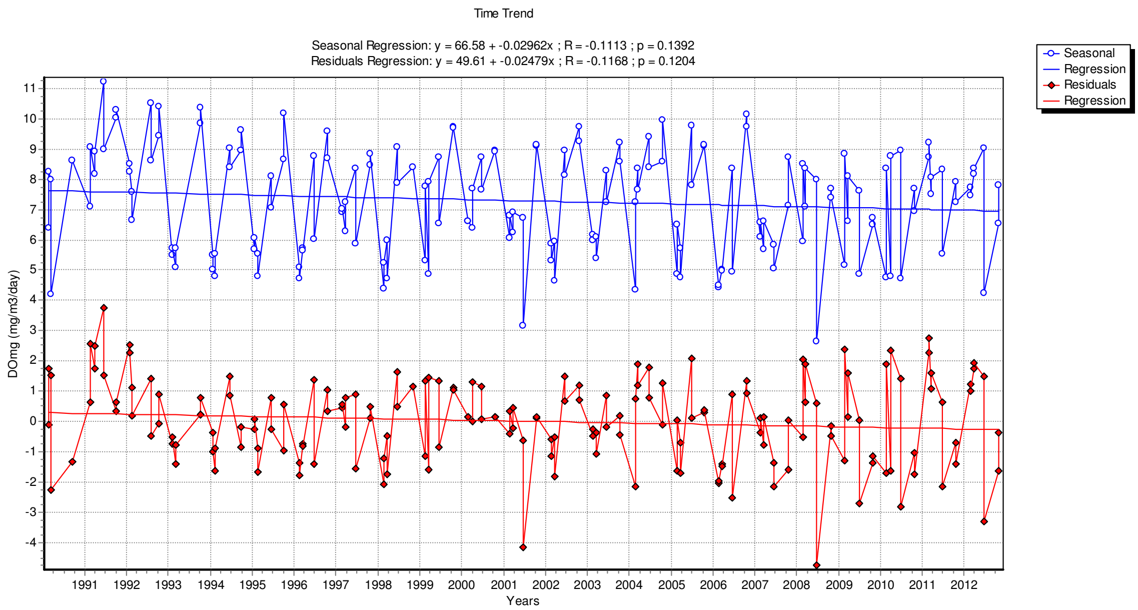
Connolly A, 2013: Trends in regional physicochemical water quality data for Taranaki: a comparison of 1995-2012 (17 year data set). TRC Internal Memo.

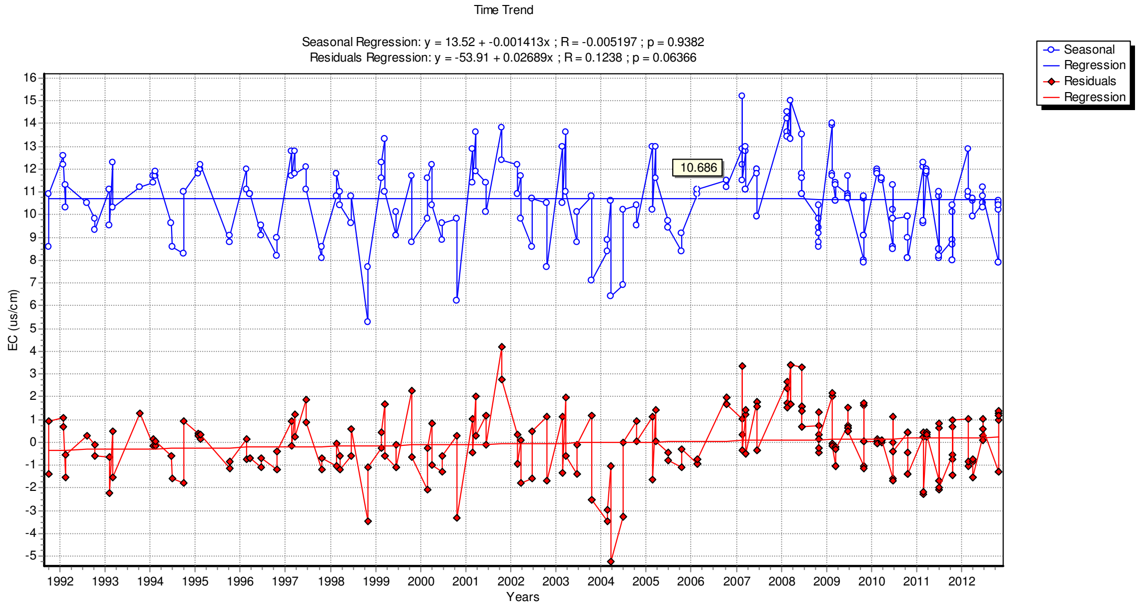
NIWA, 2011: Investigation of single indicators for water quality assessment and reporting- Prepared for the Ministry for the Environment. 108-113p.

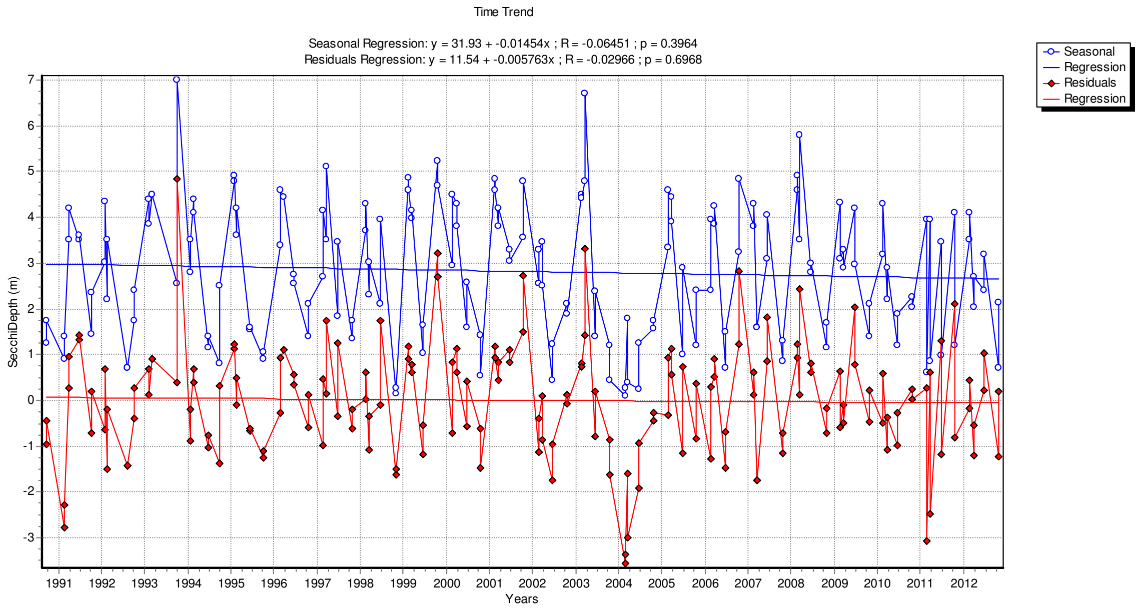
Appendix 2

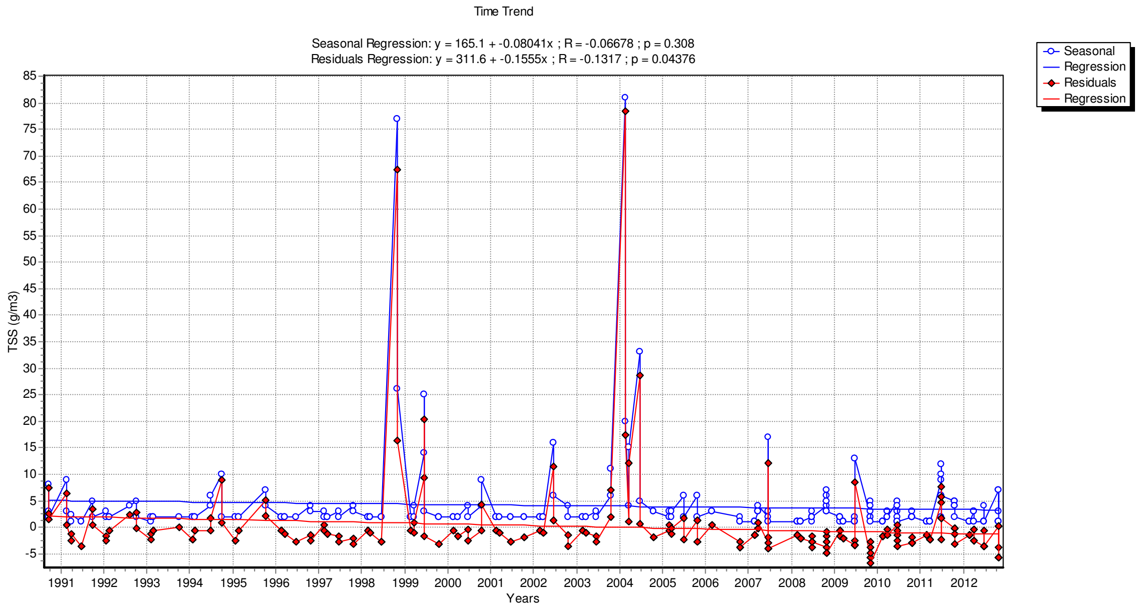
Physical parameters – Site L2 and L3 combined

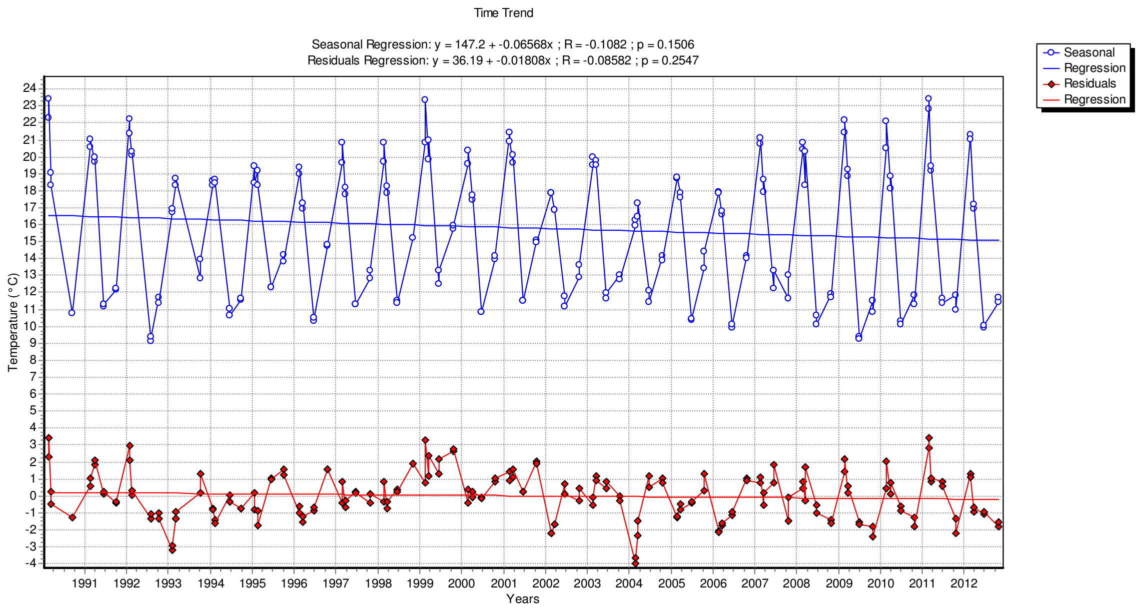




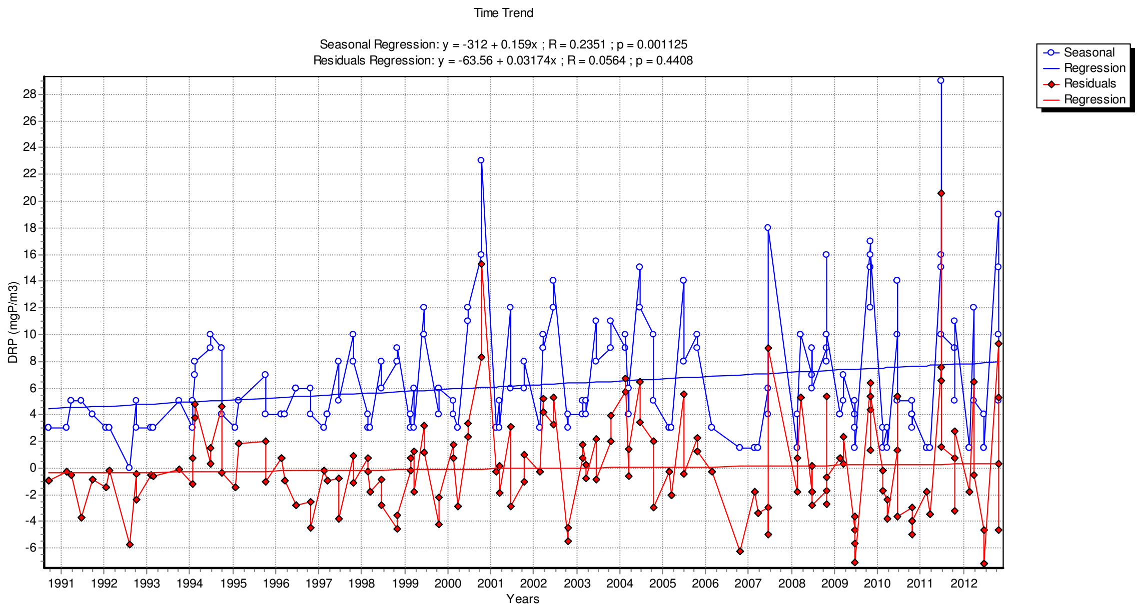

Time Trend
Seasonal Regression: y = 13.52 + -0.001413x ; R = -0.005197 ; p = 0.9382
Residuals Regression: y = -53.91 + 0.02689x ; R = 0.1238 ; p = 0.06366
Seasonal
Regression
Residuals
Regression
10.686
EC (us/cm)
Years
1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012

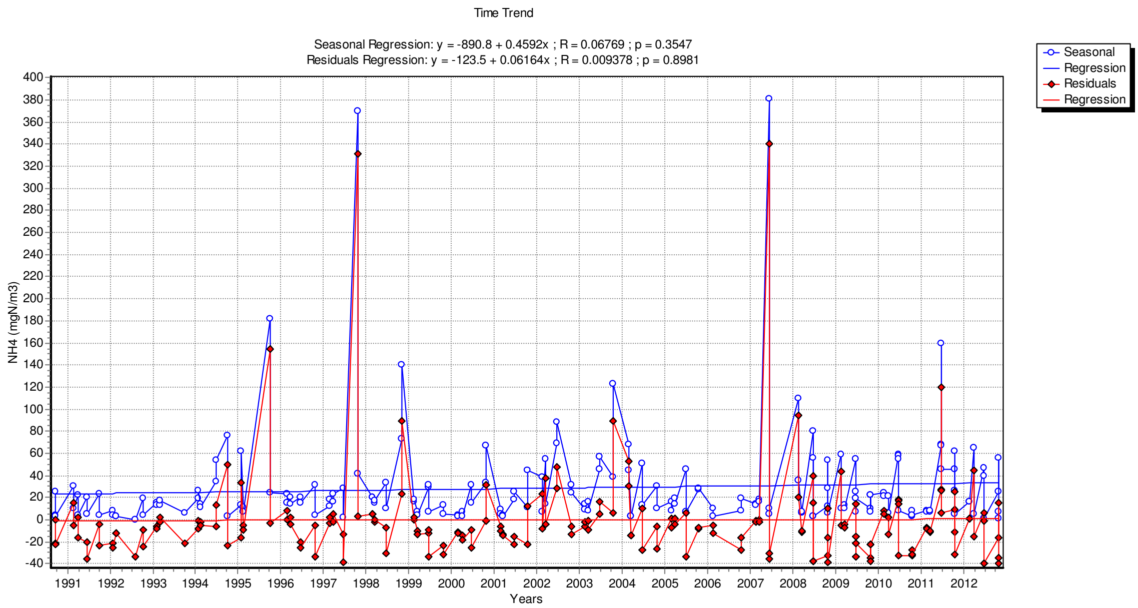

Time Trend
Seasonal Regression: y = 31.93 + -0.01454x ; R = -0.06451 ; p = 0.3964
Residuals Regression: y = 11.54 + -0.005763x ; R = -0.02966 ; p = 0.6968
Seasonal
Regression
Residuals
Regression
SecchiDepth (m)
Years
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012

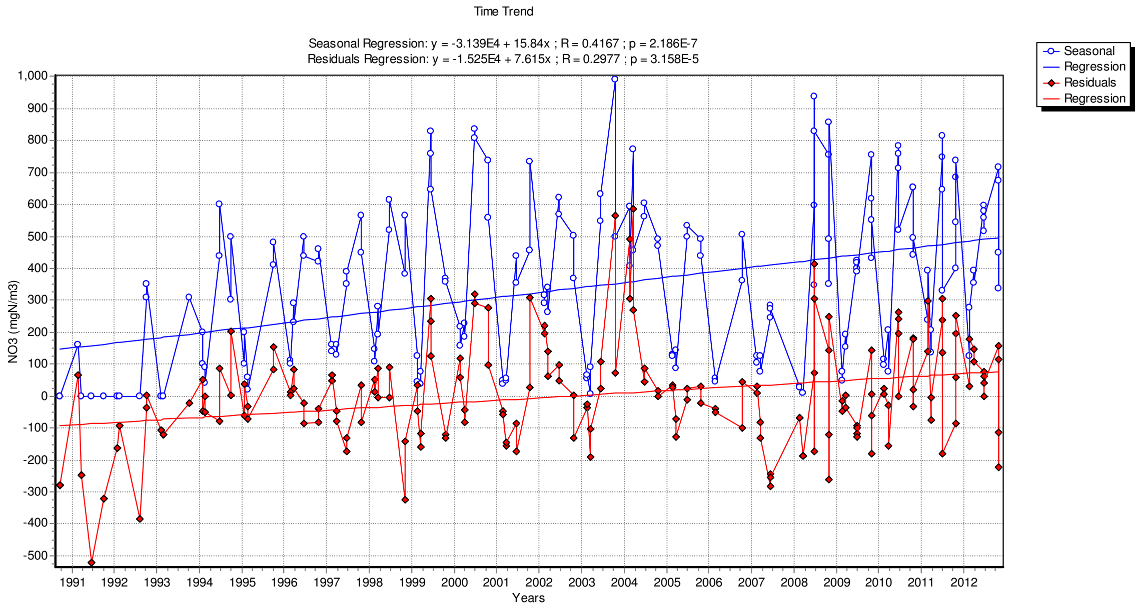

Time Trend
Seasonal Regression: y = 165.1 + -0.08041x ; R = -0.06678 ; p = 0.308
Residuals Regression: y = 311.6 + -0.1555x ; R = -0.1317 ; p = 0.04376
Seasonal
Regression
Residuals
Regression
TSS (g/m3)
Years


Time Trend
Seasonal Regression: y = 147.2 + -0.06568x ; R = -0.1082 ; p = 0.1506
Residuals Regression: y = 36.19 + -0.01808x ; R = -0.08582 ; p = 0.2547
Seasonal
Regression
Residuals
Regression
Temperature (°C)
Years

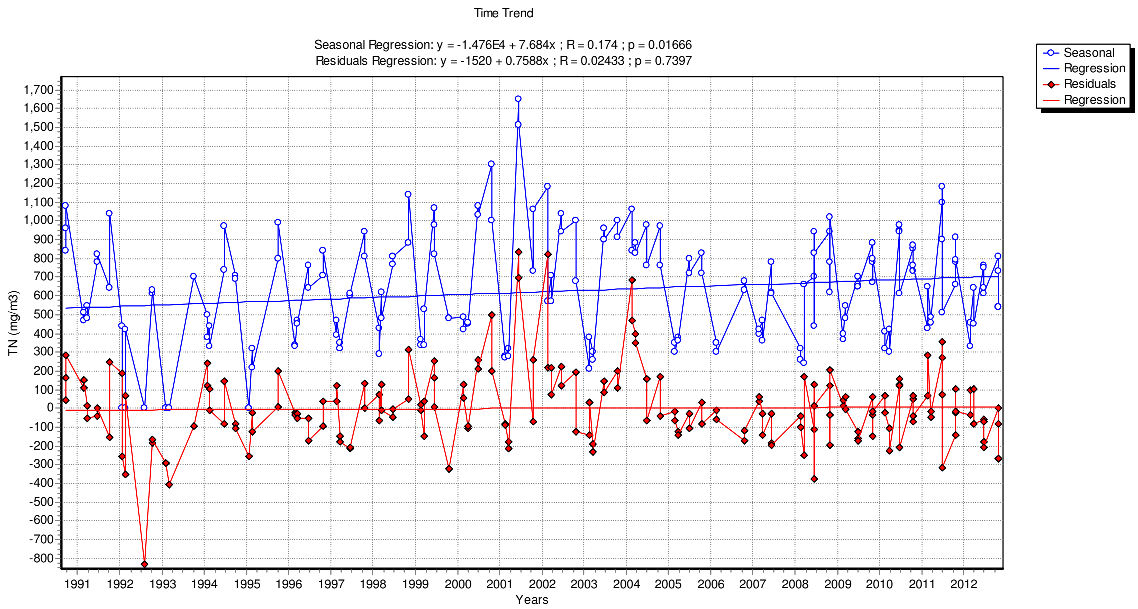
Nutrients – L2 and L3 combined





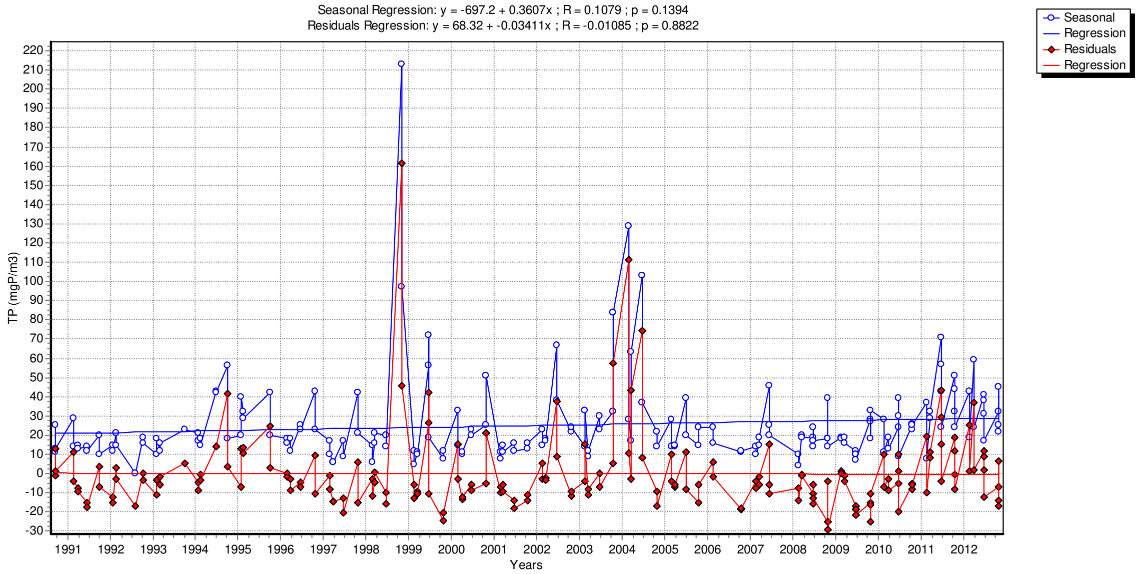


Time Trend
Seasonal Regression: y = -3.139E4 + 15.84x ; R = 0.4167 ; p = 2.186E-7
Residuals Regression: y = -1.525E4 + 7.615x ; R = 0.2977 ; p = 3.158E-5
Seasonal
Regression
Residuals
Regression
NO3 (mgN/m3)
1,000
900
800
700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
Years



Time Trend
Seasonal Regression: y = -1.476E4 + 7.684x ; R = 0.174 ; p = 0.01666
Residuals Regression: y = -1520 + 0.7588x ; R = 0.02433 ; p = 0.7397
Seasonal
Regression
Residuals
Regression
TN (mg/m3)
1,700
1,600
1,500
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
Years

Time Trend



Seasonal Regression: y = -697.2 + 0.3607x ; R = 0.1079 ; p = 0.1394
Residuals Regression: y = 68.32 + -0.03411x ; R = -0.01085 ; p = 0.8822
Seasonal
Regression
Residuals
Regression
TP (mgP/m3)
Years

HVOD Analysis

Lake: LAKE ROTORANGI

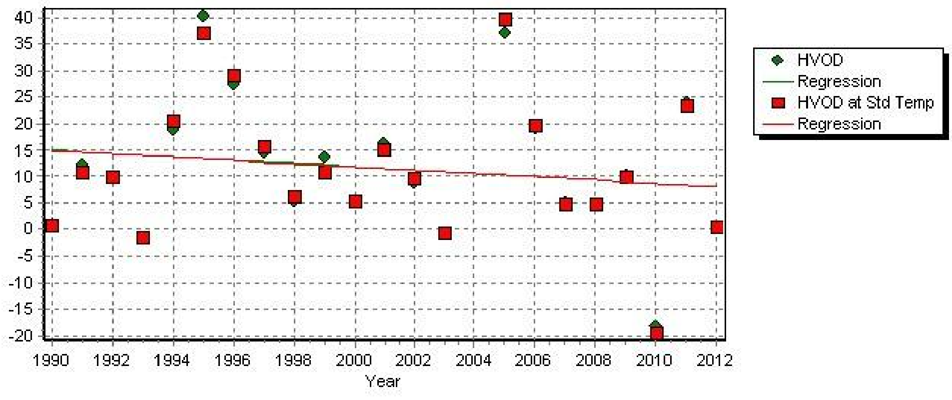
Stations: L2 (Tangahoe Valley Rd), L3 (Dam)

Date From: 1/1/1990 **Date To:** 1/1/2013

Analysis Period			Average	Observed DO	Observed Rate Corrected to 9.9 °C (mg/m3/day)
01-Jan-1997	-	31-Mar-1997	8.66	14.5	15.8
01-Jan-1998	-	31-Mar-1998	8.31	5.6	6.3
01-Jan-1999	-	31-Mar-1999	13.32	13.7	10.8
01-Jan-2000	-	04-Apr-2000	10.12	5.6	5.5
01-Jan-2001	-	31-Mar-2001	11.08	16.4	15.1
01-Jan-2002	-	31-Mar-2002	8.73	8.9	9.7
01-Jan-2003	-	31-Mar-2003	9.66	-0.4	-0.4
01-Jan-2005	-	31-Mar-2005	8.94	37.0	39.6
01-Jan-2006	-	31-Mar-2006	9.42	19.1	19.8
01-Jan-2007	-	31-Mar-2007	10.19	5.1	5.0
01-Jan-2008	-	30-Mar-2008	9.49	4.8	4.9
01-Jan-2009	-	31-Mar-2009	10.06	10.2	10.1
01-Jan-2010	-	31-Mar-2010	8.97	-18.0	-19.2
01-Jan-2011	-	31-Mar-2011	10.25	24.0	23.4
01-Jan-2012	-	30-Mar-2012	9.77	0.6	0.6
01-Jan-1990	-	31-Mar-1990	10.51	1.1	1.0
01-Jan-1991	-	31-Mar-1991	11.59	12.3	10.9
01-Jan-1992	-	30-Mar-1992	9.85	10.1	10.2
01-Jan-1993	-	31-Mar-1993	9.4	-1.2	-1.2
01-Jan-1994	-	31-Mar-1994	8.55	18.8	20.6
01-Jan-1995	-	31-Mar-1995	11.1	40.2	37.0
01-Jan-1996	-	30-Mar-1996	8.94	27.3	29.2
Average			**9.86**	**11.6**	**11.6**

HVOD Rate

HVOD Regression: y = 643 + -0.3156x ; R = -0.1666 ; p = 0.4587
HVOD at 9.9°C Regression: y = 629.6 + -0.3089x ; R = -0.1607 ; p = 0.4751



LAKE ROTORANGI

L2 & L3 1990-2013 (1 Jan 1990 - 1 Jan 2013)

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	(0.05)	(-0.01)	(-0.03)	(0.76)	(-0.37)			
Average Over Period	(2.97)	(2.82)	(25.28)	(627.62)	(11.58)			
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	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			
Jan 2012 - Dec 2012	3.33	2.60	33.00	605.00	3.55	4.41	4.65	4.76	4.34	0.28			
Averages	**2.93**	**2.79**	**24.77**	**624.00**	**3.35**	**4.37**	**4.19**	**4.73**	**4.16**	**0.07**	**0.02**	**0.01**	**0.1462**

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

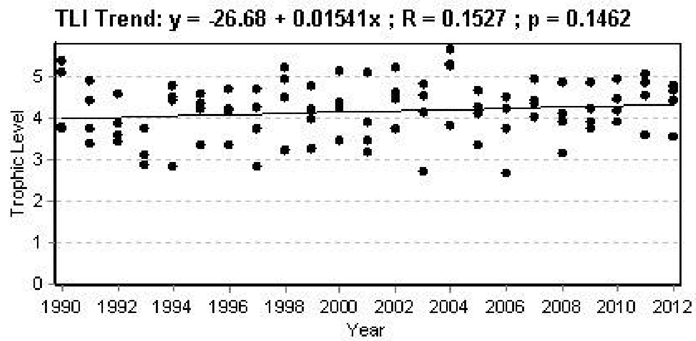
TLI Value = 4.16 ± 0.07 TLI units
TLI Trend = 0.02 ± 0.01 TLI units per year
P-Value = 0.1462

ASSESSMENT:

Eutrophic
No Change

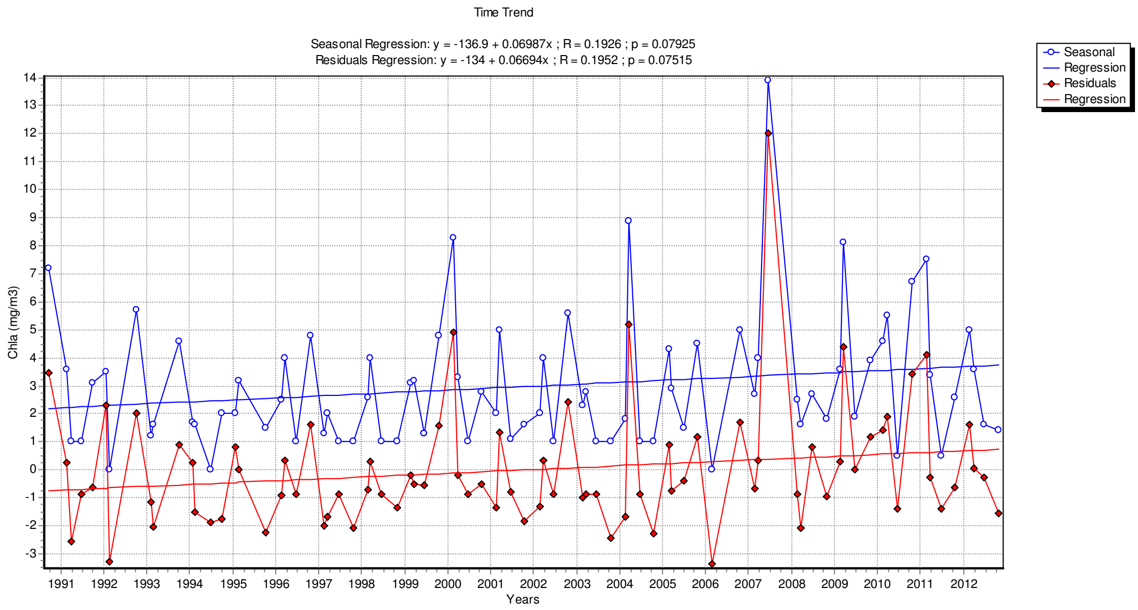
The guide used in the PAC average P-Value evaluation is

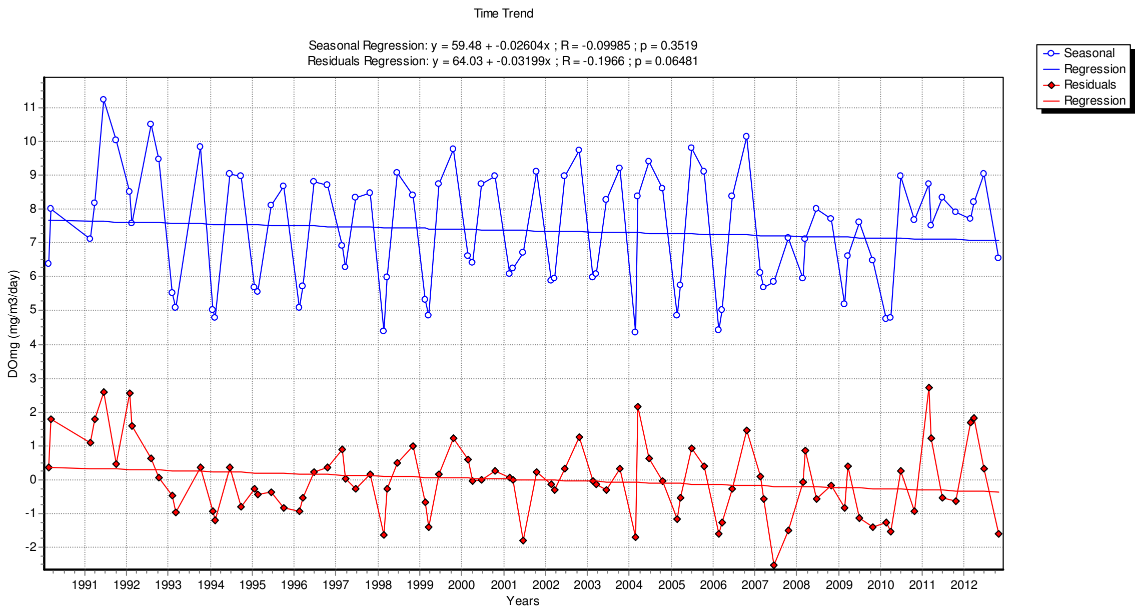
P-Value Range	Interpretation
P ≤ 0.1	Definite Change
0.1 < P ≤ 0.2	Probable Change
0.2 < P ≤ 0.3	Possible Change
0.3 < P	No Change

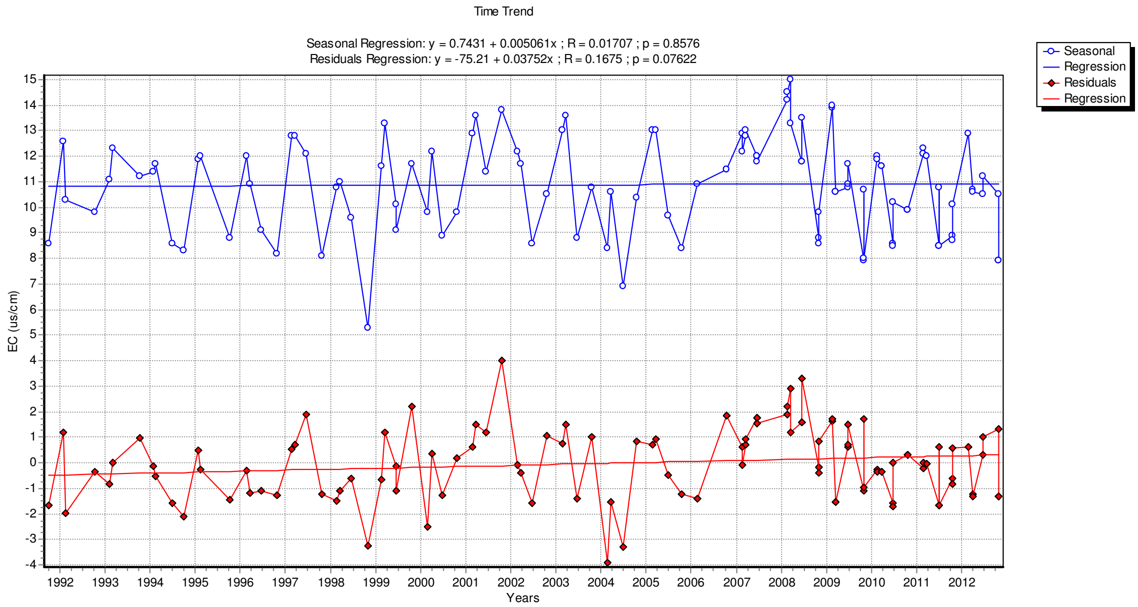


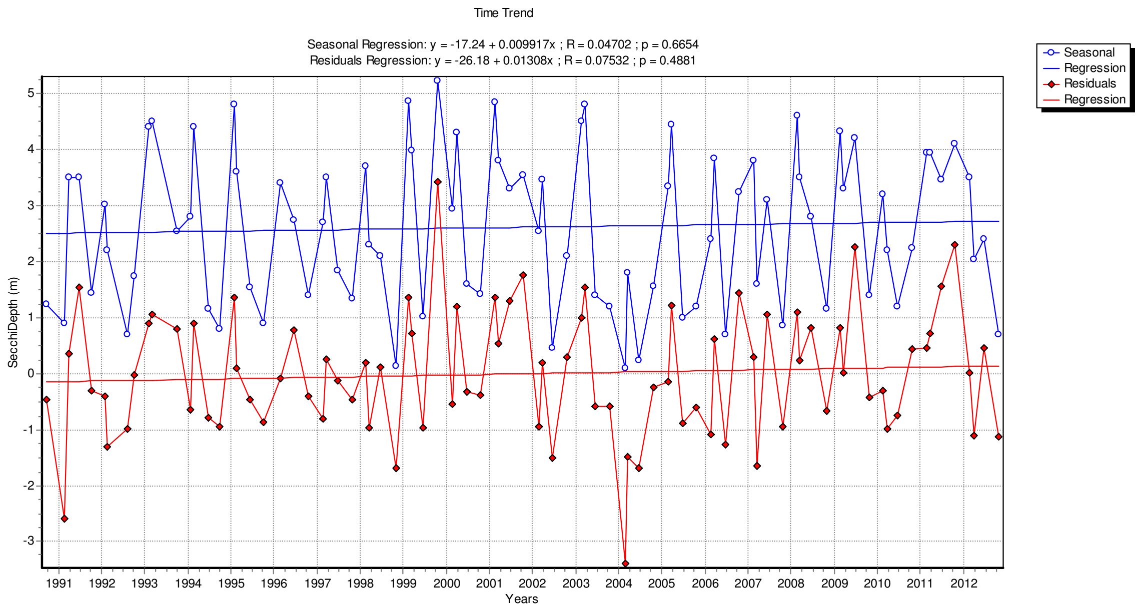
Appendix 3

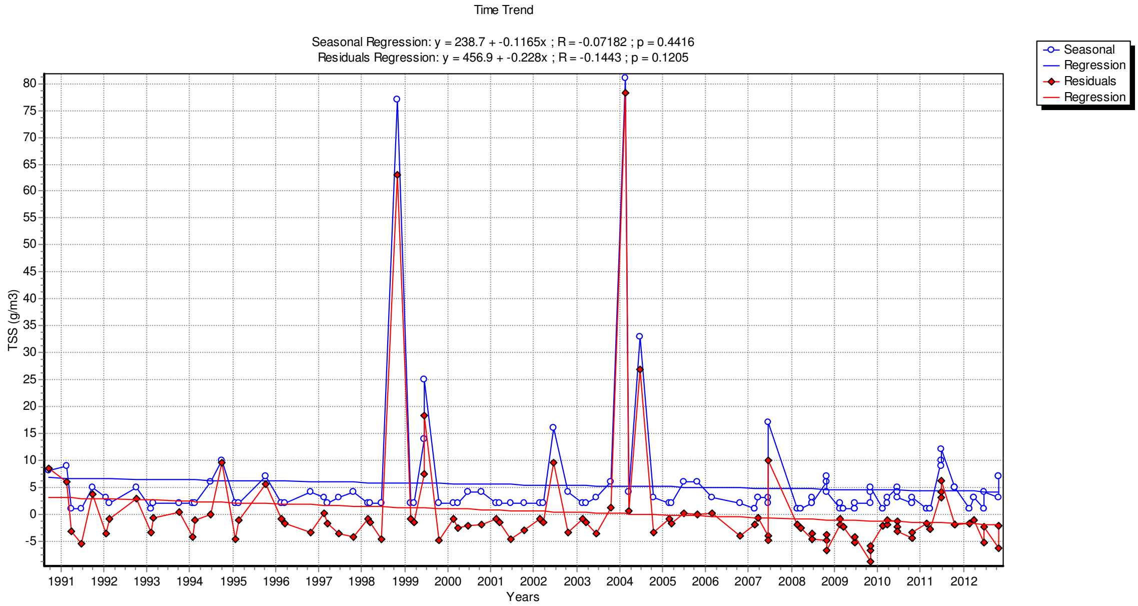
Physical Parameters – Site L2 trends



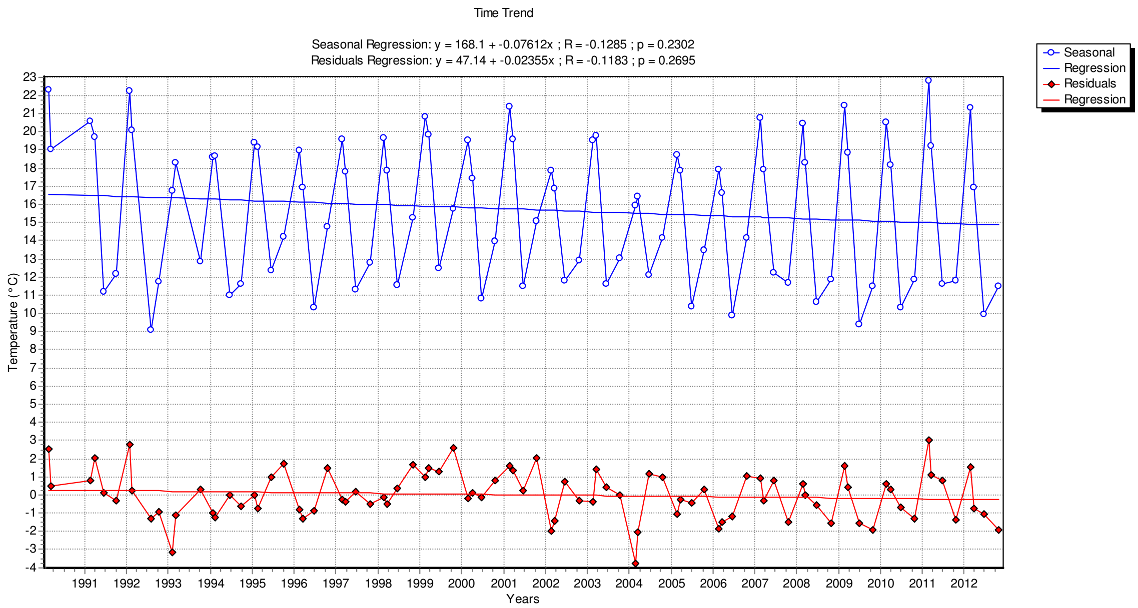



Time Trend
Seasonal Regression: y = 0.7431 + 0.005061x ; R = 0.01707 ; p = 0.8576
Residuals Regression: y = -75.21 + 0.03752x ; R = 0.1675 ; p = 0.07622
Seasonal
Regression
Residuals
Regression
EC (us/cm)
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0 -1 -2 -3 -4
1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
Years


Time Trend
Seasonal Regression: y = -17.24 + 0.009917x ; R = 0.04702 ; p = 0.6654
Residuals Regression: y = -26.18 + 0.01308x ; R = 0.07532 ; p = 0.4881
Seasonal
Regression
Residuals
Regression
SecchiDepth (m)
5 4 3 2 1 0 -1 -2 -3
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
Years

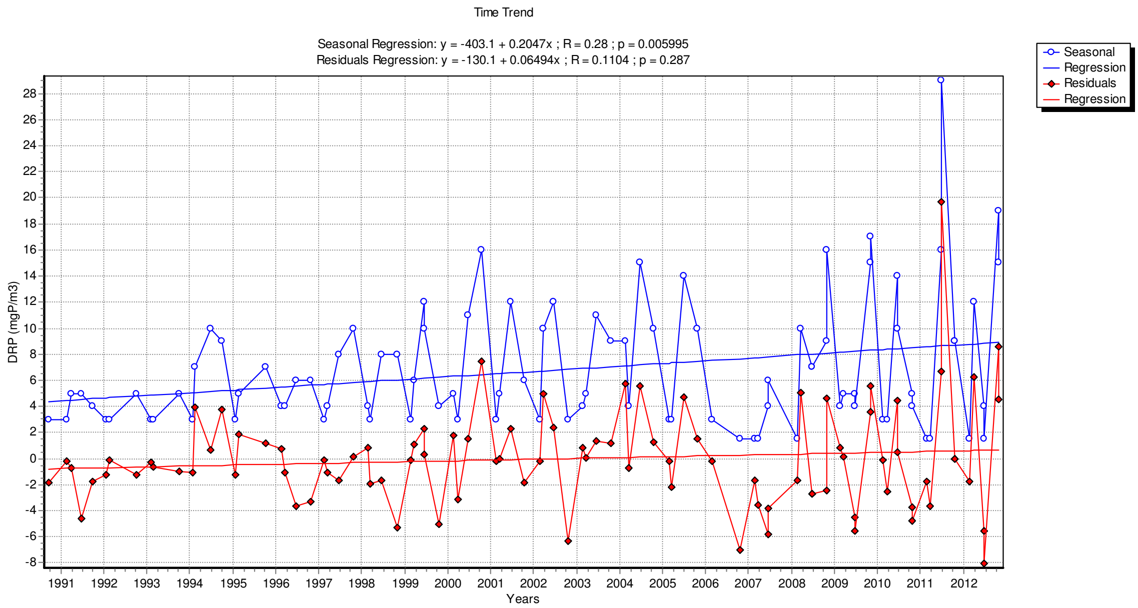


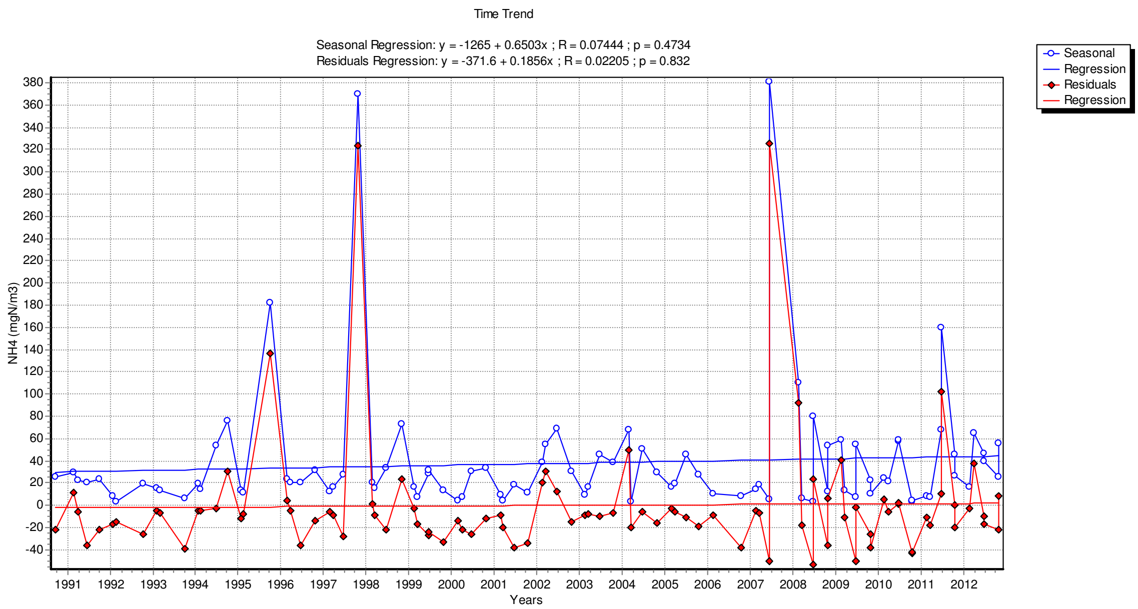
Time Trend
Seasonal Regression: y = 238.7 + -0.1165x ; R = -0.07182 ; p = 0.4416
Residuals Regression: y = 456.9 + -0.228x ; R = -0.1443 ; p = 0.1205
Seasonal
Regression
Residuals
Regression
TSS (g/m3)
Years

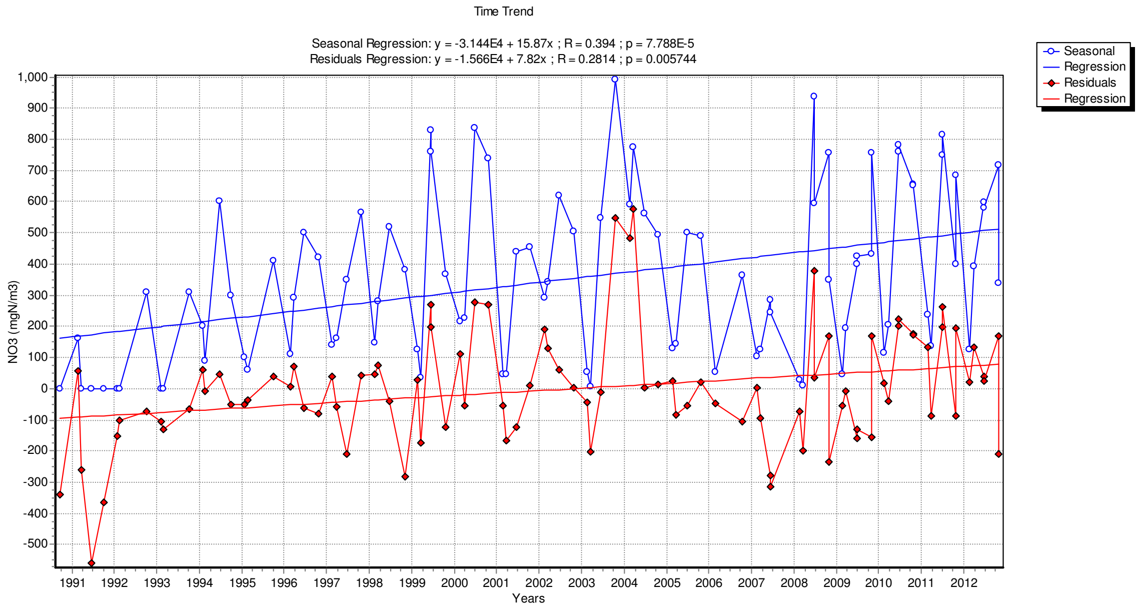


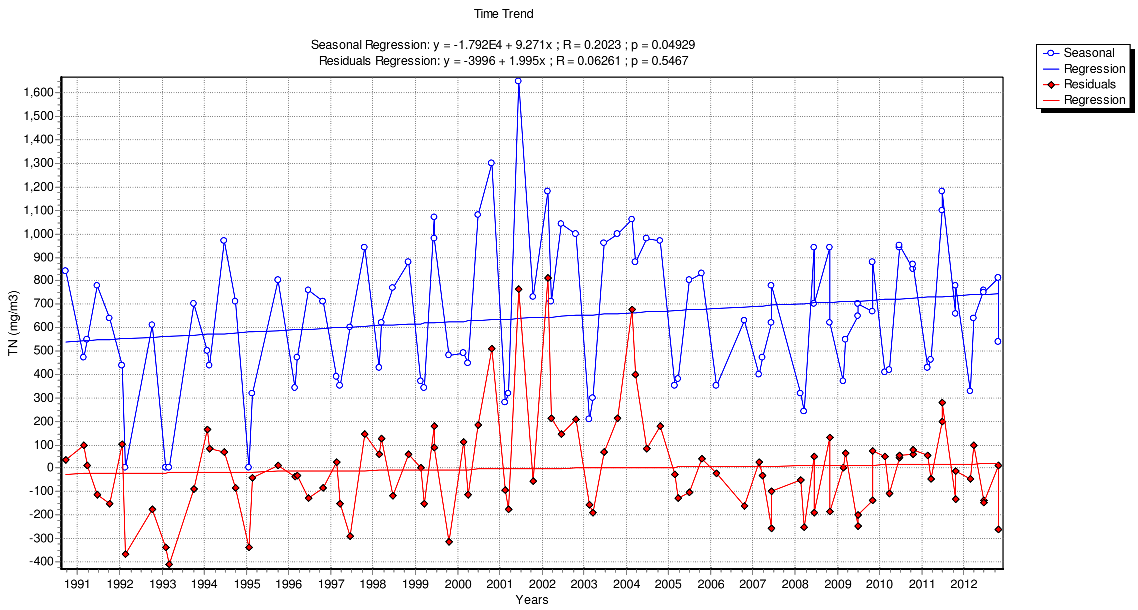
Time Trend
Seasonal Regression: y = 168.1 + -0.07612x ; R = -0.1285 ; p = 0.2302
Residuals Regression: y = 47.14 + -0.02355x ; R = -0.1183 ; p = 0.2695
Seasonal
Regression
Residuals
Regression
Temperature (°C)
Years

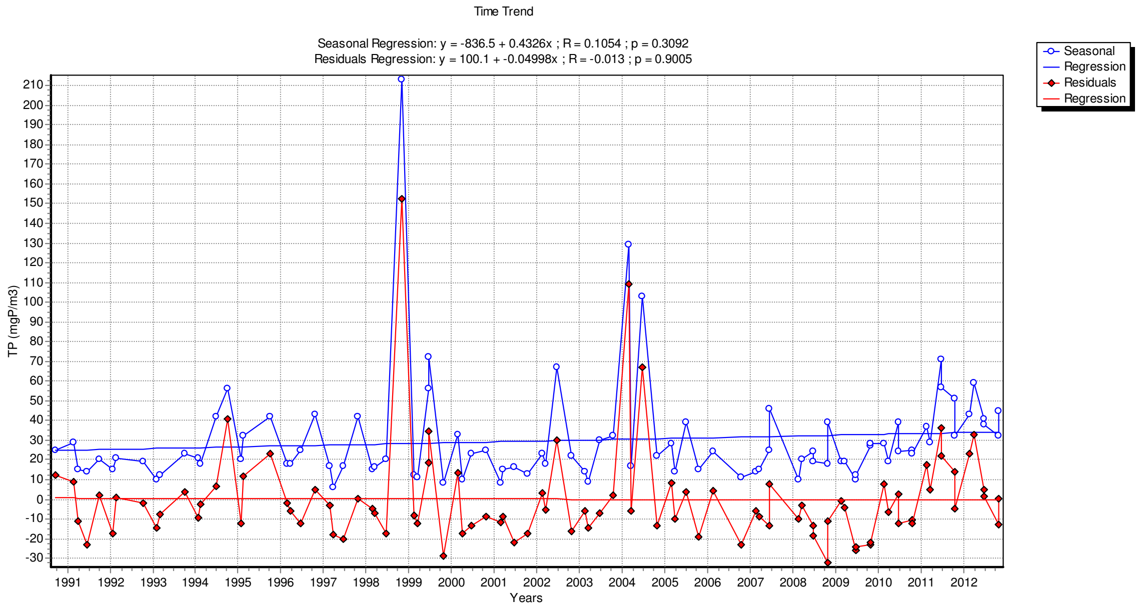
Nutrients – Site L2 trends






Time Trend
Seasonal Regression: y = -3.144E4 + 15.87x ; R = 0.394 ; p = 7.788E-5
Residuals Regression: y = -1.566E4 + 7.82x ; R = 0.2814 ; p = 0.005744
Seasonal
Regression
Residuals
Regression
NO3 (mgN/m3)
Years


Time Trend
Seasonal Regression: y = -1.792E4 + 9.271x ; R = 0.2023 ; p = 0.04929
Residuals Regression: y = -3996 + 1.995x ; R = 0.06261 ; p = 0.5467
Seasonal
Regression
Residuals
Regression
TN (mg/m3)
Years



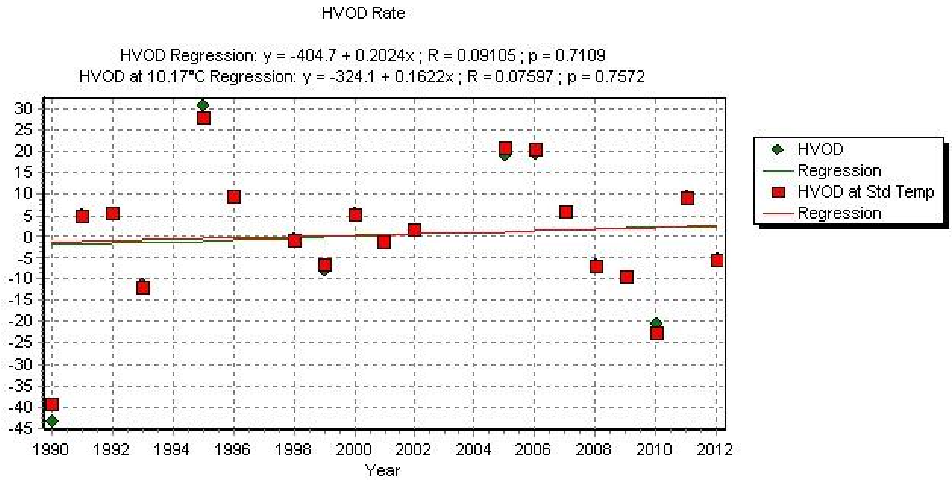
Time Trend
Seasonal Regression: y = -836.5 + 0.4326x ; R = 0.1054 ; p = 0.3092
Residuals Regression: y = 100.1 + -0.04998x ; R = -0.013 ; p = 0.9005
TP (mgP/m3)
Years
Seasonal
Regression
Residuals
Regression

HVOD Analysis

Lake: LAKE ROTORANGI
Stations: L2 (Tangahoe Valley Rd)

Date From: 1/1/1990 **Date To:** 1/1/2013

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	-38.9
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	27.8
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	20.6
01-Jan-2006 - 31-Mar-2006	9.51	19.4	20.3
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	-22.2
01-Jan-2011 - 31-Mar-2011	10.63	9.5	9.2
01-Jan-2012 - 30-Mar-2012	9.97	-5.2	-5.3
Average	**10.17**	**0.3**	**0.4**



LAKE ROTORANGI

L2 1990-2013 (1 Jan 1990 - 1 Jan 2013)

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	(0.07)	(0.01)	(-0.05)	(2.00)	(0.16)			
Average Over Period	(2.97)	(2.62)	(29.91)	(651.89)	(0.43)			
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	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			
Jan 2012 - Dec 2012	2.90	2.16	43.00	638.33	3.39	4.63	4.99	4.83	4.46	0.36			
Averages	**3.06**	**2.58**	**29.17**	**647.49**	**3.37**	**4.47**	**4.38**	**4.79**	**4.25**	**0.07**	**0.01**	**0.01**	**0.3061**

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

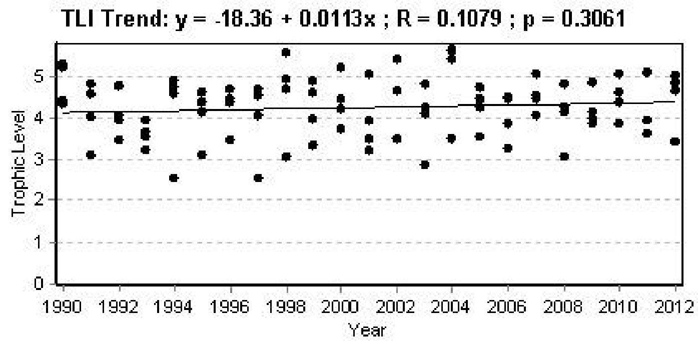
TLI Value = 4.25 ± 0.07 TLI units
TLI Trend = 0.01 ± 0.01 TLI units per year
P-Value = 0.3061

ASSESSMENT:

Eutrophic
No Change

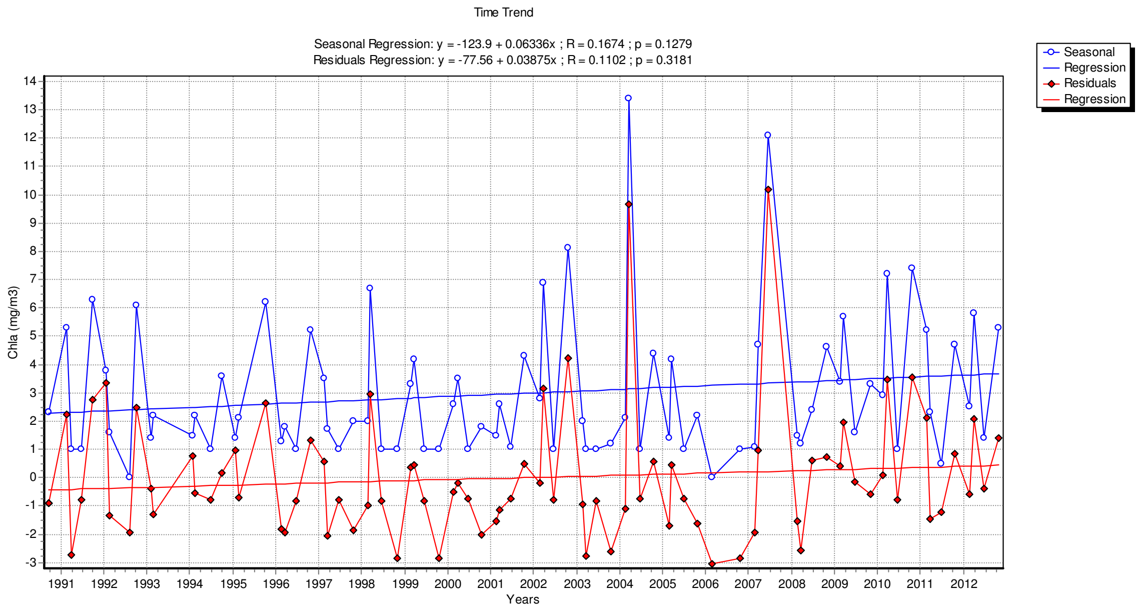
The guide used in the PAC average P-Value evaluation is

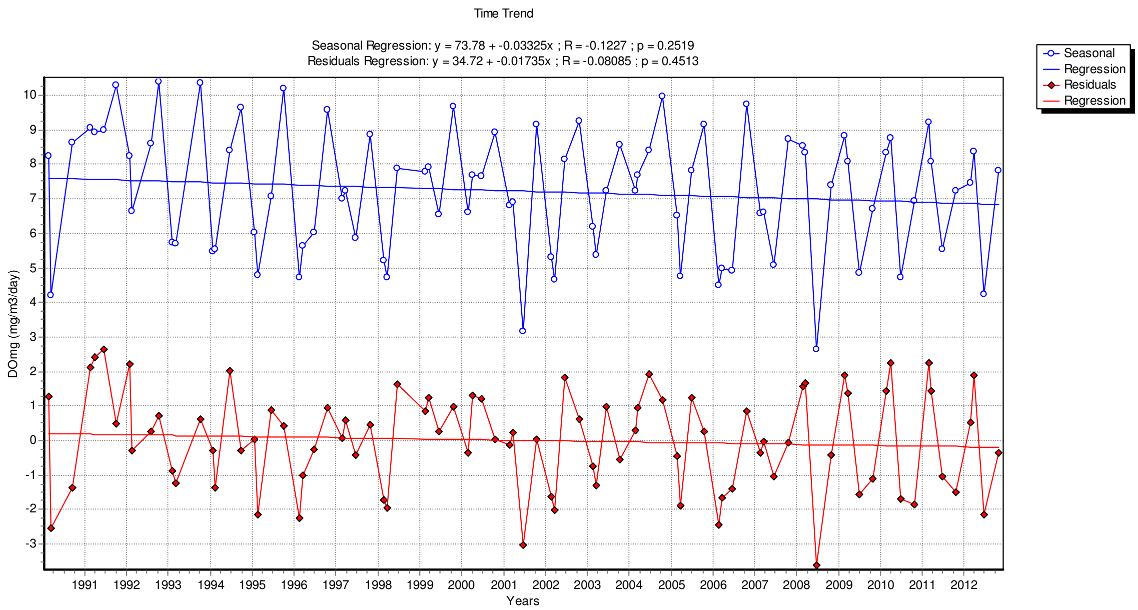
P-Value Range	Interpretation
$P \leq 0.1$	Definite Change
$0.1 < P \leq 0.2$	Probable Change
$0.2 < P \leq 0.3$	Possible Change
$0.3 < P$	No Change

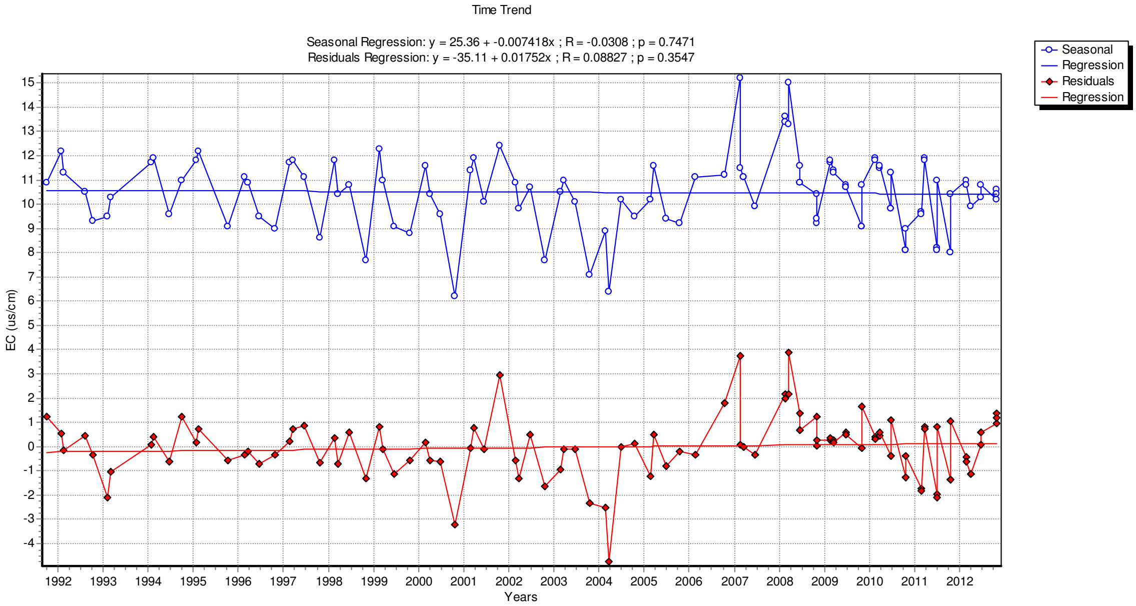


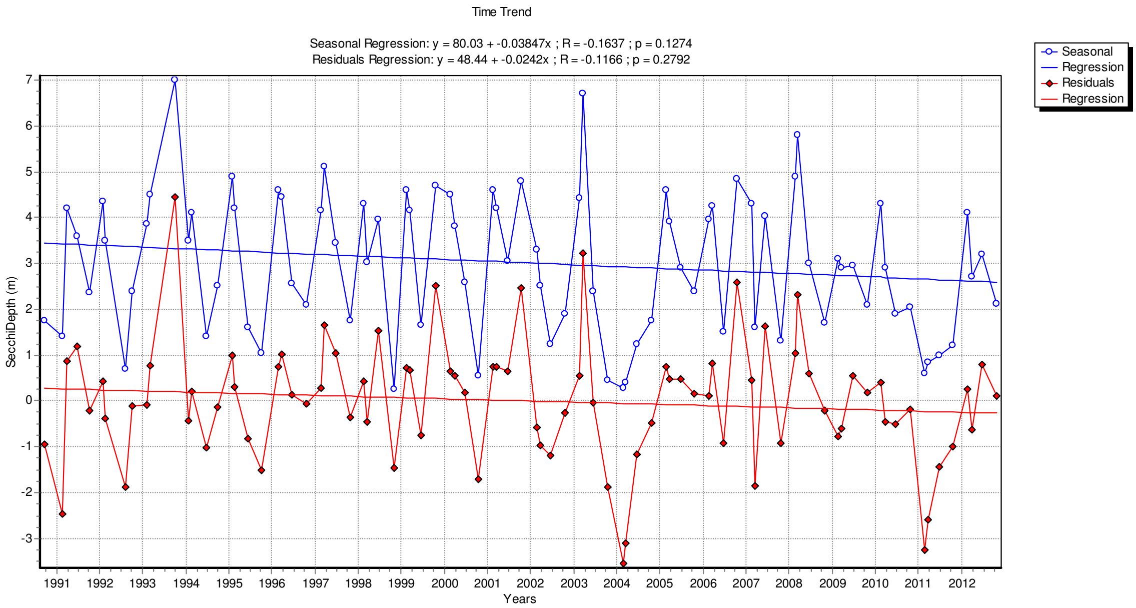
Appendix 4

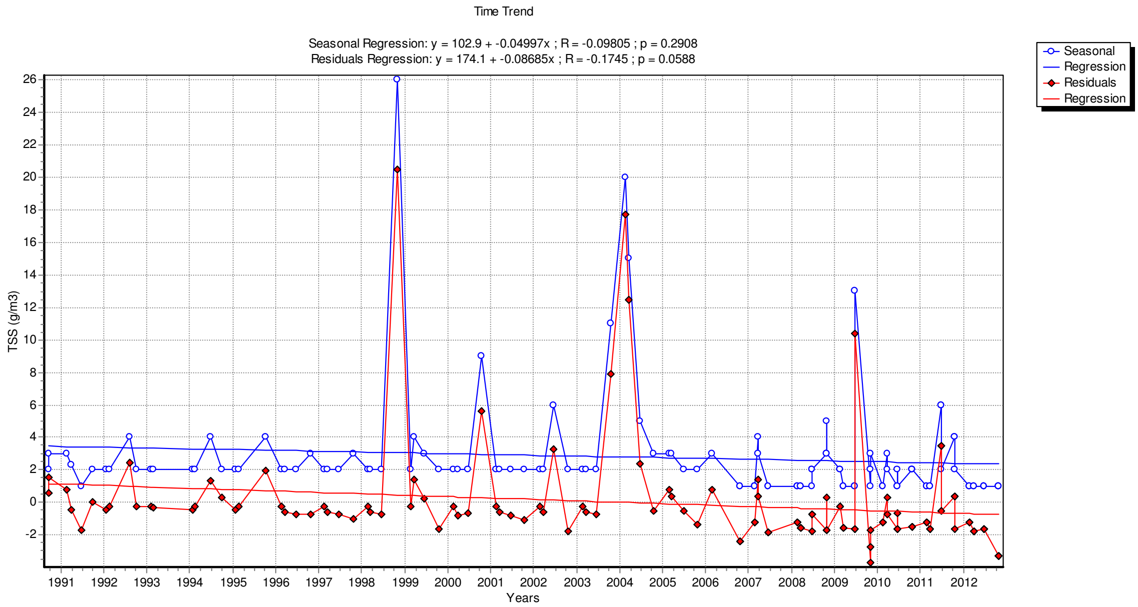
Physical parameters – Site L3 Trends



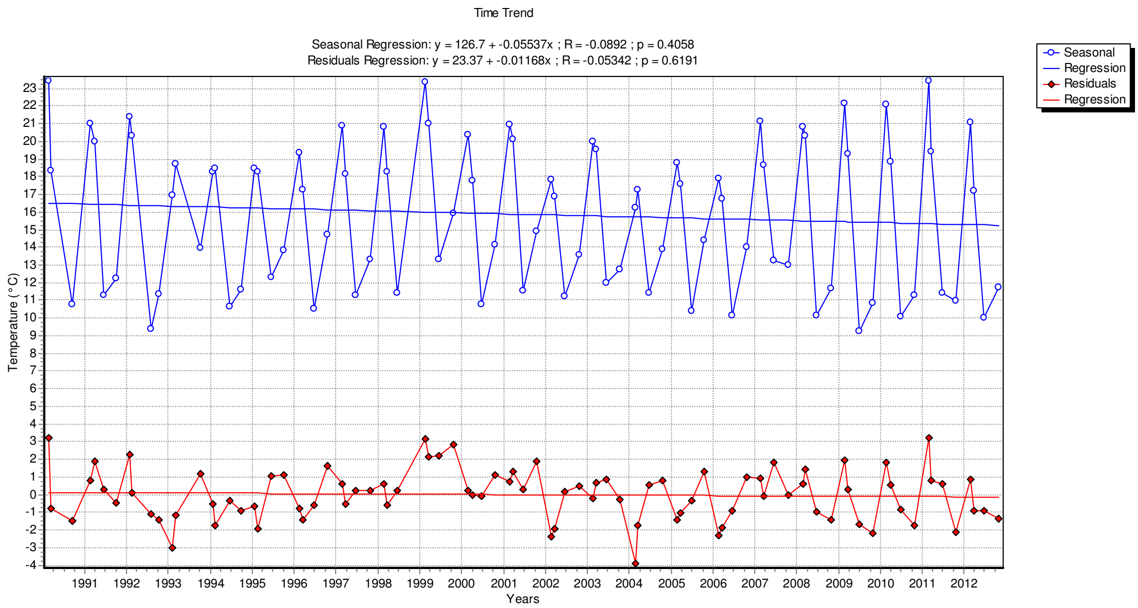



Time Trend
Seasonal Regression: y = 25.36 + -0.007418x ; R = -0.0308 ; p = 0.7471
Residuals Regression: y = -35.11 + 0.01752x ; R = 0.08827 ; p = 0.3547
Seasonal
Regression
Residuals
Regression
EC (us/cm)
Years
1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012


Time Trend
Seasonal Regression: y = 80.03 + -0.03847x ; R = -0.1637 ; p = 0.1274
Residuals Regression: y = 48.44 + -0.0242x ; R = -0.1166 ; p = 0.2792
Seasonal
Regression
Residuals
Regression
SecchiDepth (m)
Years
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012

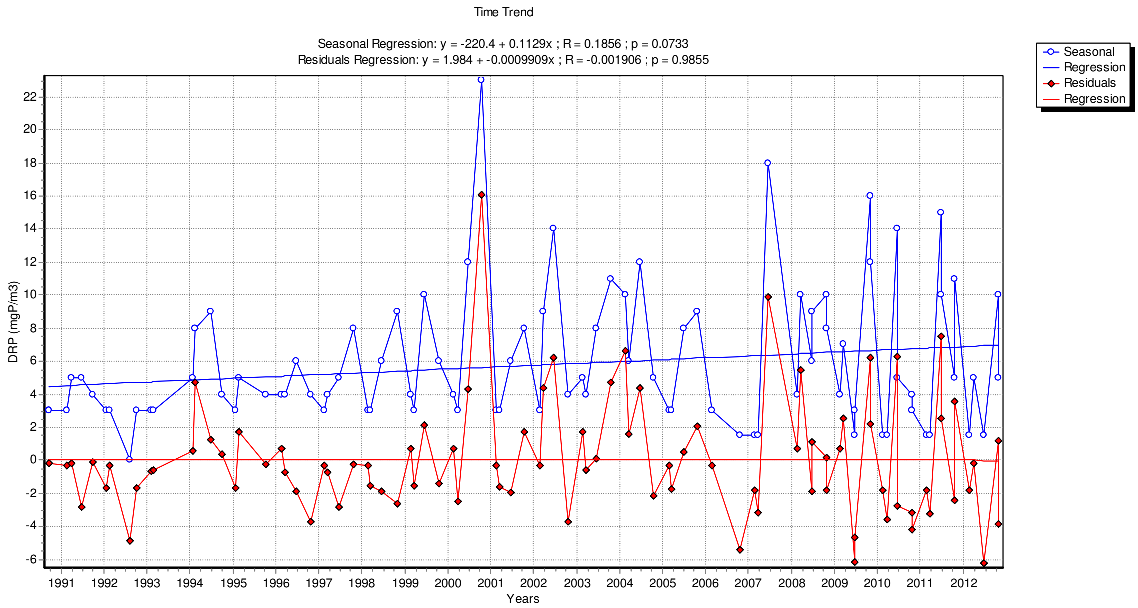


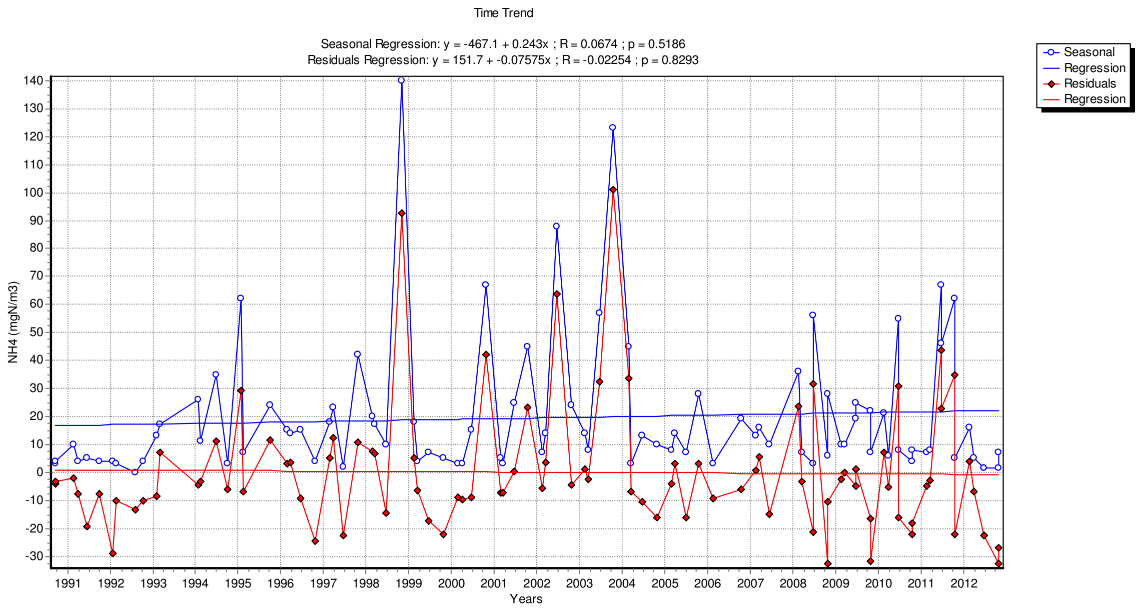
Time Trend
Seasonal Regression: y = 102.9 + -0.04997x ; R = -0.09805 ; p = 0.2908
Residuals Regression: y = 174.1 + -0.08685x ; R = -0.1745 ; p = 0.0588
Seasonal
Regression
Residuals
Regression
TSS (g/m3)
Years

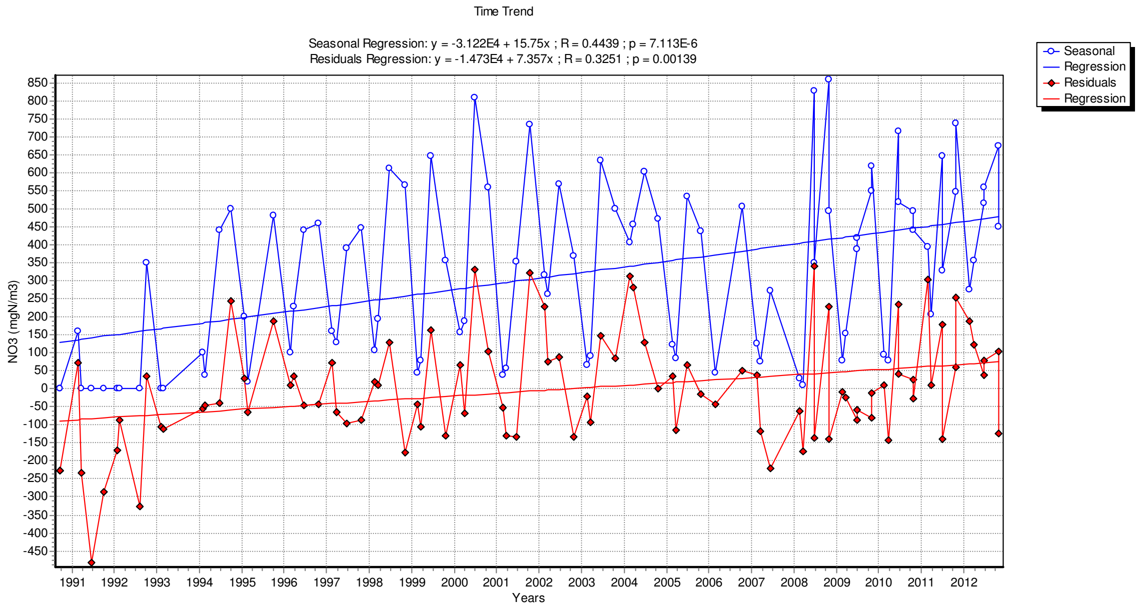


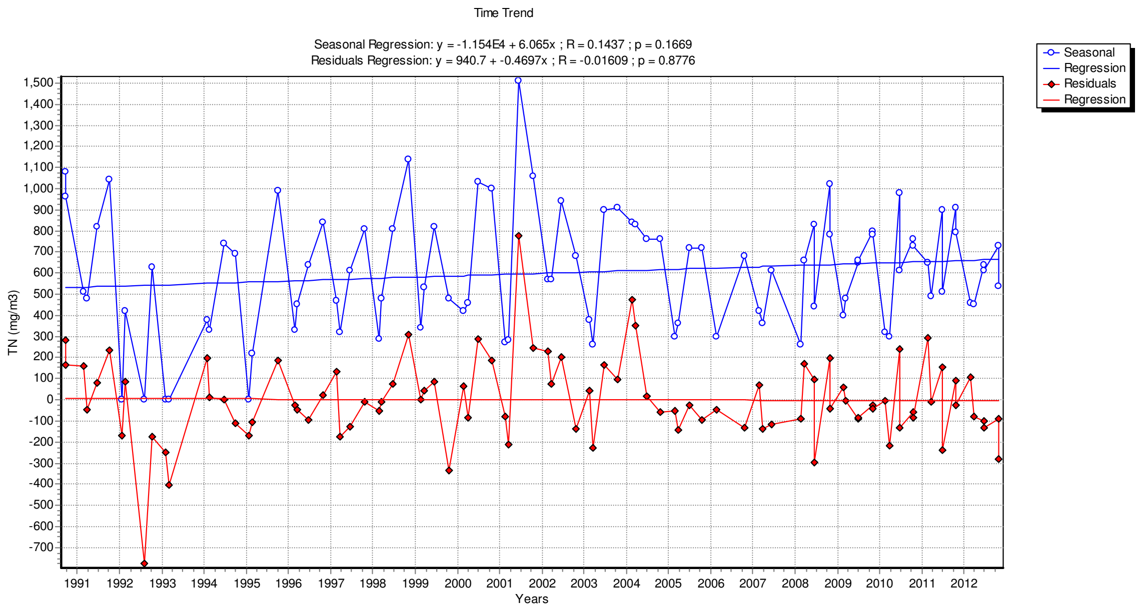
Time Trend
Seasonal Regression: y = 126.7 + -0.05537x ; R = -0.0892 ; p = 0.4058
Residuals Regression: y = 23.37 + -0.01168x ; R = -0.05342 ; p = 0.6191
Seasonal
Regression
Residuals
Regression
Temperature (°C)
Years

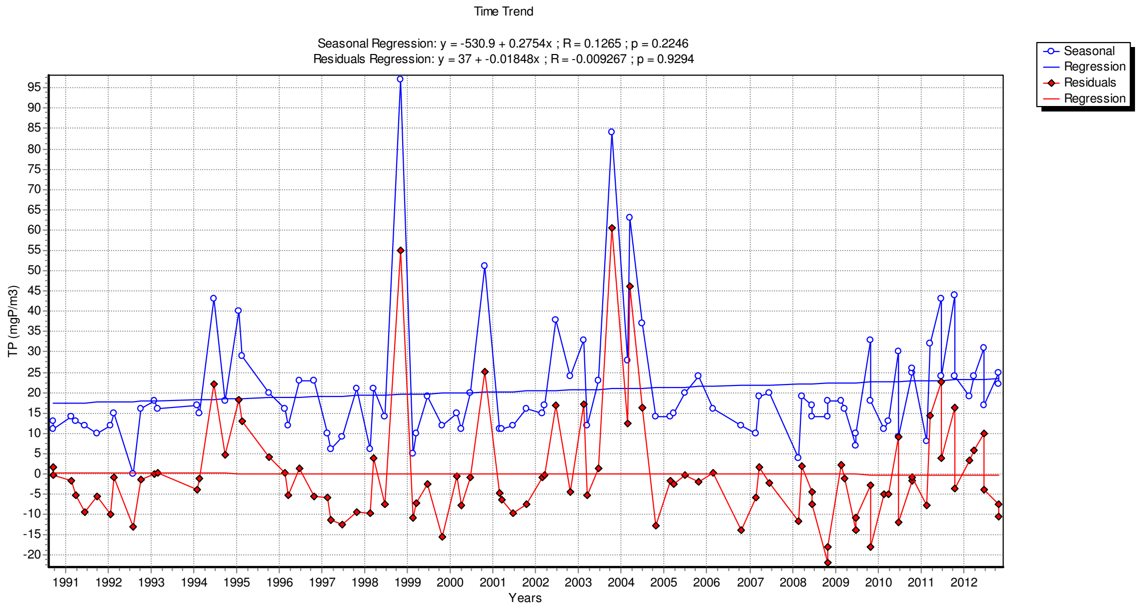
Nutrients – Site L3 Trends






Time Trend
Seasonal Regression: y = -3.122E4 + 15.75x ; R = 0.4439 ; p = 7.113E-6
Residuals Regression: y = -1.473E4 + 7.357x ; R = 0.3251 ; p = 0.00139
Seasonal
Regression
Residuals
Regression
NO3 (mgN/m3)
Years


Time Trend
Seasonal Regression: y = -1.154E4 + 6.065x ; R = 0.1437 ; p = 0.1669
Residuals Regression: y = 940.7 + -0.4697x ; R = -0.01609 ; p = 0.8776
Seasonal
Regression
Residuals
Regression
TN (mg/m3)
Years


Time Trend
Seasonal Regression: y = -530.9 + 0.2754x ; R = 0.1265 ; p = 0.2246
Residuals Regression: y = 37 + -0.01848x ; R = -0.009267 ; p = 0.9294
Seasonal
Regression
Residuals
Regression
TP (mgP/m3)
Years

HVOD Analysis

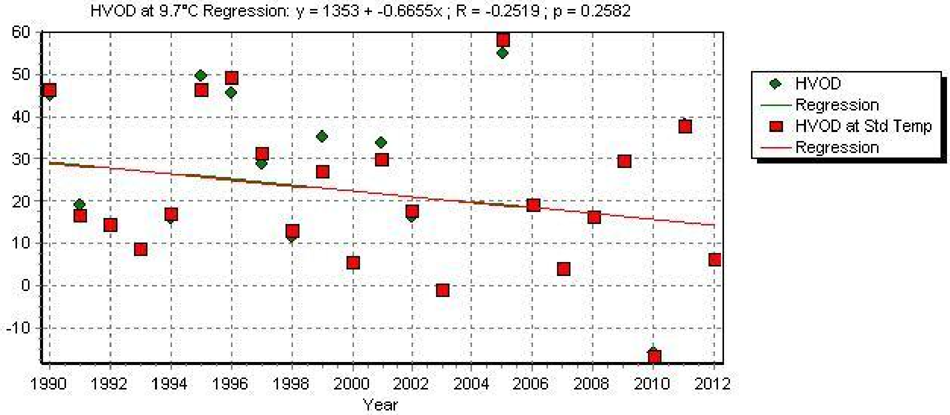
Lake: LAKE ROTORANGI
Stations: L3 (Dam)

Date From: 1/1/1990 **Date To:** 1/1/2013

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-2003 - 31-Mar-2003	9.47	-0.8	-0.8
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
01-Jan-2012 - 30-Mar-2012	9.57	6.3	6.4
Average	**9.70**	**22.0**	**21.9**

HVOD Rate

HVOD Regression: y = 1373 + -0.6751x ; R = -0.258 ; p = 0.2464
HVOD at 9.7°C Regression: y = 1353 + -0.6655x ; R = -0.2519 ; p = 0.2582



LAKE ROTORANGI

L3 1990-2013 (1 Jan 1990 - 1 Jan 2013)

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)	(-0.02)	(-0.02)	(-0.47)	(-0.67)			
Average Over Period	(2.97)	(3.01)	(20.60)	(603.09)	(21.89)			
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			
Jan 2012 - Dec 2012	3.75	3.03	23.00	571.67	3.68	4.22	4.19		4.03	0.18			
Averages	**2.86**	**3.00**	**20.45**	**594.71**	**3.27**	**4.31**	**3.95**		**3.84**	**0.08**	**0.02**	**0.01**	**0.1672**

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 = 0.1672

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