State of the Environment Monitoring of Lake Rotorangi water quality and biological programme Annual Report 2015-2016

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Executive summary

Lake Rotorangi was formed in May 1984 by the construction of an earth fill dam on the Patea River. 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, a comprehensive monitoring programme was developed and implemented for the lake. This report presents the results of the twenty-sixth year of this monitoring.

Four water quality sampling surveys were performed at two sites during the 2015-2016 period. The first of the two sites surveyed is located in the mid reaches of the lake, while the second site is located nearer to the dam.

Changes in thermal stratification during the year were largely similar to that typically recorded in previous surveys of this reservoir-type lake. Thermal stratification was beginning to form at both sites during the spring survey, and was well developed during the late summer - autumn at the mid and lower lake sites, with dissolved oxygen depletion measured in the lower waters of the hypolimnion at both sites. 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. These conditions have been typical of this reservoir-type lake on most occasions to date.

During the monitoring year phytoplankton richnesses (diversity) were low to moderate, coincident with low to moderate chlorophyll-a levels. 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 has been 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. This component of the programme has been reduced in frequency for future monitoring purposes.

An autumn 2015 macrophyte survey identified the oxygen weed *Egeria densa* as the dominant macrophyte throughout the majority of the lake. Only two other species were recorded as dominant in particular areas, being *Lagarosiphon major* and *Ceratophyllum demersum* (hornwort). This is the second record of hornwort in Lake Rotorangi and its distribution had increased markedly since its first record in early 2012. It is expected that hornwort will 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. The next macrophyte survey of Lake Rotorangi is due to be performed in the 2017-2018 period.

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 sediment in this reservoir, and the moderately low chlorophyll levels, the classification is more appropriately mesotrophic. Previous trending of these water quality data over time found a very slow rate of increase in trophic level. An update of the trend report (for the period 1990-2015) has confirmed this very slow, insignificant rate of increase in trophic level. This also confirmed that the lake would be classified as mesotrophic in terms of its biological condition.

The monitoring programme will continue in its present format for state of the environment reporting purposes with regular (3-yearly) additional biological components (e.g. macrophyte survey) for consent compliance purposes. This report also includes recommendations for the 2016-2017 monitoring year.

Table of contents

List of tables

List of figures

List of photos

1. Introduction

1.1 General

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 comprises 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) was published in 2009 (TRC, 2009a) and included trend reporting. The fourth report (for the period 1995 to 2013) was published in 2015 (TRC, 2015a). The provision of appropriate statistical software now allows regular reporting on trends in environmental quality over time where there has been an accumulation of a comprehensive dataset of sufficient duration to permit a meaningful analysis to be undertaken (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 intermediate 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 Taranaki Catchment 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 had settled down, it was 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-six Annual Reports and four subsequent state of the environment reports. An opportunity was also taken (in mid 1995) to review the appropriateness of the monitoring programme and the results obtained over the seven years of its operation in this format. NIWA (as consultant to the 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 trophic 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 a consent renewal process which was progressed during the 2007-2010 period. The Council has subsequently re-analysed the water quality trends over the 1990-2015 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).

The Patea Catchment above the dam (including the Mangaehu sub catchment) covers an area of 86,944.3 ha, with an urban area of 840.9 ha (1%). Riparian plans have been prepared for an area of 18,983.0 ha (22% of catchment). As at June 2016, some 200 riparian plans have been prepared by the Council in relation to properties within the Patea River sub-catchment. An additional four plans have been produced for properties in the Mangaehu River sub-catchment, upstream of the lake. Within these plans, some 865 km of Patea riverbank [68% of the total banks' length] and 19 km of Mangaehu stream banks [46%] currently have adequate riparian protection provided on the properties covered by the plans. This represents an increase of 40 km in the Patea catchment and 2 km in the Mangaehu catchment over the past year. Outside of the properties covered by riparian plans there are a further 51% 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 riparian plan. Within the catchment area, 46,908.9 ha (54%) is covered by Hill Country plans, addressing land management and sediment issues. This area is dominated by dry stock properties, as well as 6,588.7ha (8%) of DOC owned land and is located to the northeast and south east of the catchment.

1.3 Trends in lake water quality

As referenced in Section 1.2, the 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 25 year period 1990-2015 (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 (0.01 $\pm$ 0.01 TLI units per year). Of the key variables (chlorophyll-a, secchi disc, total phosphorus and total nitrogen), only chlorophyll-a trended significantly, increasing slowly, within the mesotrophic level range. Other variables showing significant temporal trends were dissolved oxygen, temperature and nitrate, all increasing.

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 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 as required for future lake monitoring and state of the environment trending requirements.

1.4.3 Lake Rotorangi biological monitoring

Phytoplankton monitoring was performed at the same two sites sampled for physicochemical analysis, on all four of the lake sampling visits. Macroinvertebrate samples collected in the past from the lake bed at these two sites during the spring physicochemical survey were not collected in 2015, as this component of the programme has been reduced in frequency. The aquatic macrophyte survey of the lake, last performed during autumn 2012, was repeated in autumn 2015.

1.5 Objective

The objective of this Annual Report is to present the results of the 2015-2016 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.

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 the locations of 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 **General site code**	**1729856E 5626435N** **LRT 000300**	**1734948E 5621974N** **LRT 000450**
Depth profile[1] for		
- dissolved oxygen	X	X
- temperature	X	X
Point source[2] in the:		
(a) Surface, for	[LRT00S300]	[LRT00S450]
- secchi disc transparency	X	X
- black disc transparency	X	X
- pH	X	X
- conductivity	X	X
- turbidity	X	X
- suspended solids	X	X
- chlorophyll-a[3]	X	X
- *E. coli*	X	X
(b) Epilimnion, and	[LRT00E300]	[LRT00E450]
(c) Hypolimnion, for	[LRT00H300]	[LRT00H450]
- suspended solids	X	X
- total phosphorus	X	X
- dissolved reactive phosphorus	X	X
- nitrate-nitrogen	X	X
- nitrite-nitrogen	X	X
- ammoniacal-nitrogen	X	X
- total Kjeldahl nitrogen	X	X
- total nitrogen	X	X
- pH	X	X
- conductivity	X	X
- turbidity	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
- pH	X	X
- turbidity	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*

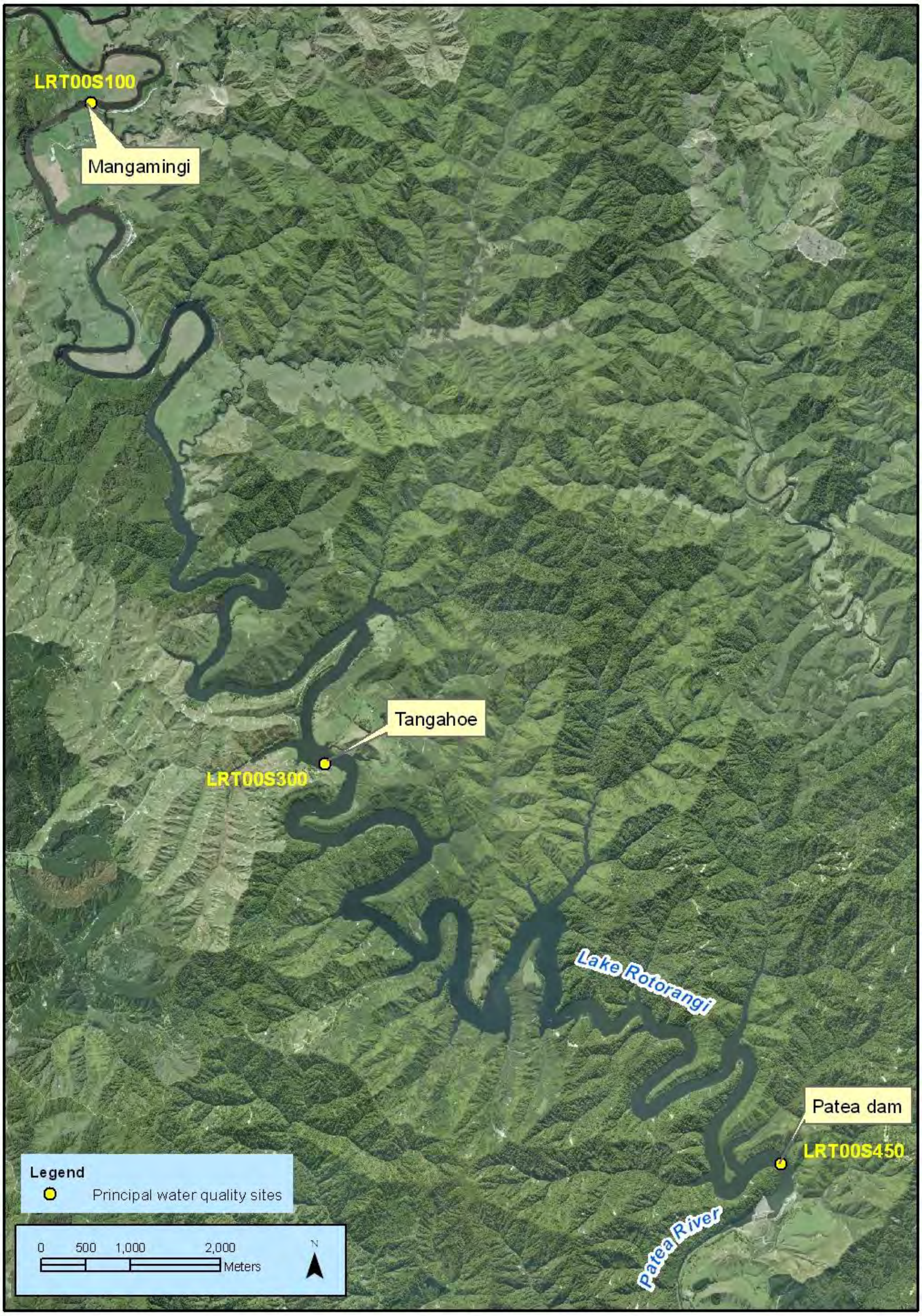

Figure 1 Aerial location map of Lake Rotorangi water quality sampling sites for 2015-2016 [LRT000300 and LRT000450]

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	23 October 2015
2	Late summer, stratification	24 February 2016
3	Autumn, stratification	22 March 2016
4	Winter	20 June 2016

The spring sampling survey was performed under steady fresh recession river flow conditions following a small fresh three weeks earlier (see Figure 2 and Figure 3 and Appendix I). The late summer survey occurred under low river recession flow conditions following a fresh six days earlier in the upper Patea catchment, after a dry period over the preceding three weeks. The autumn survey was performed under steady fresh recession flow conditions four days since the previous small fresh, after a dry period over the preceding four weeks. The final (winter) survey was performed during steady fresh river recession flow conditions seven and nine days after two freshes, and after a wet period of six freshes in both catchments over the preceding six weeks. Lake level was moderate at the time of the spring (75.9 m asl), late summer (76.7 m asl) and autumn (76.4 m asl) surveys, and very high during the winter survey (77.6 m asl).

Flow data for the Patea River, Mangaehu River and synthesised inflow to Lake Rotorangi are presented in Figure 2, Figure 3 and Figure 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.

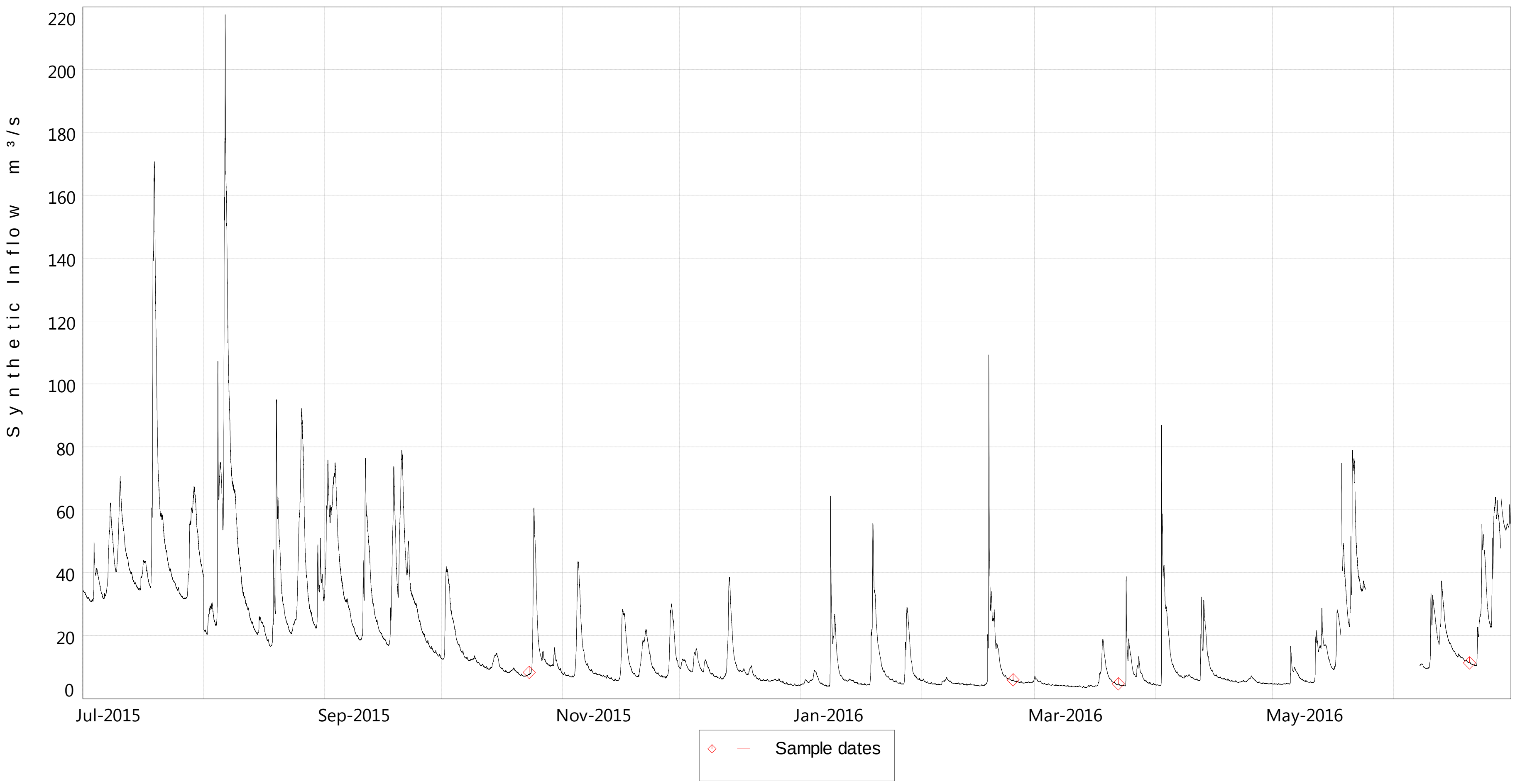

Figure 2 Synthetic inflow at Lake Rotorangi for the period 1 July 2015 to 30 June 2016

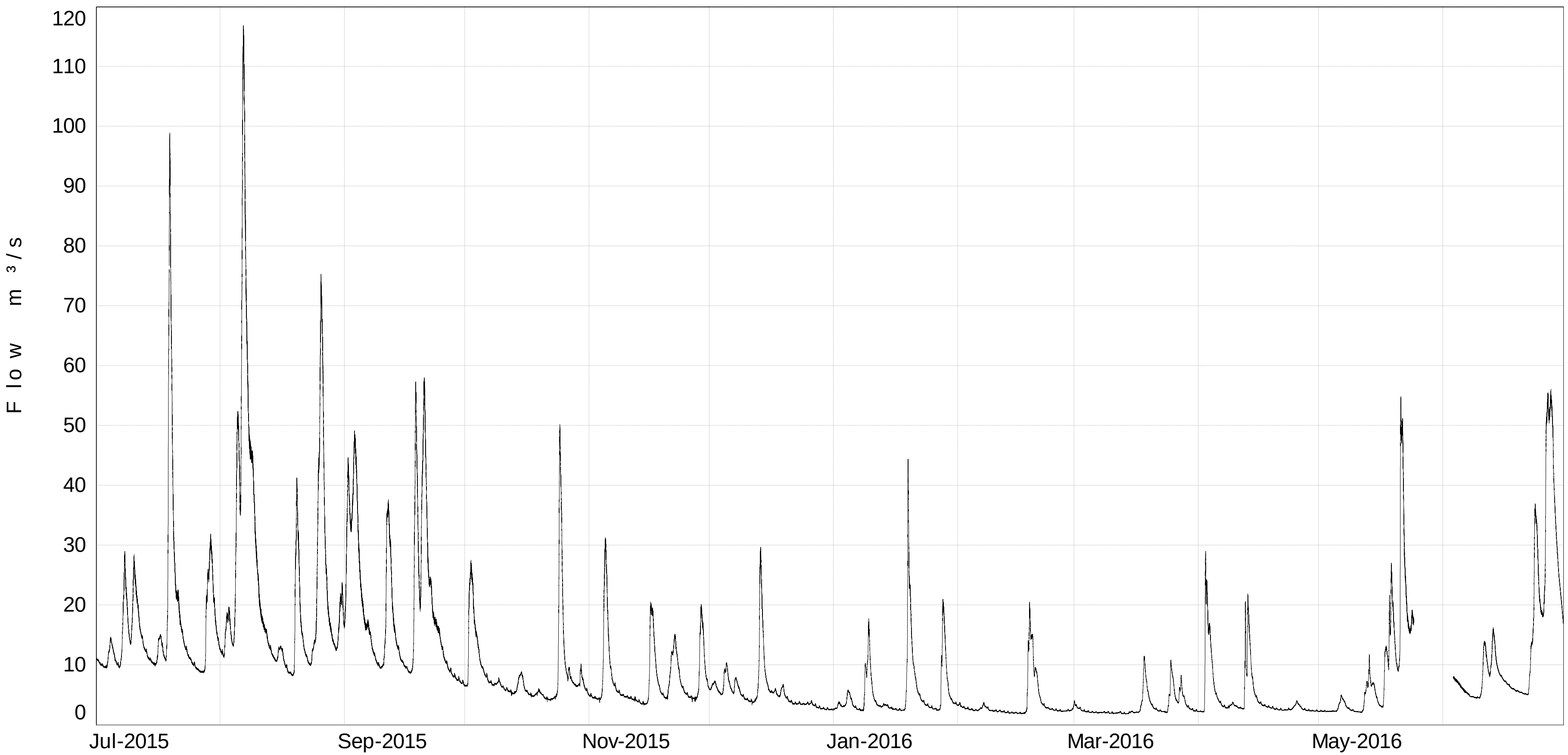

Figure 3 Flow in the Mangaehu River from July 2015 to June 2016

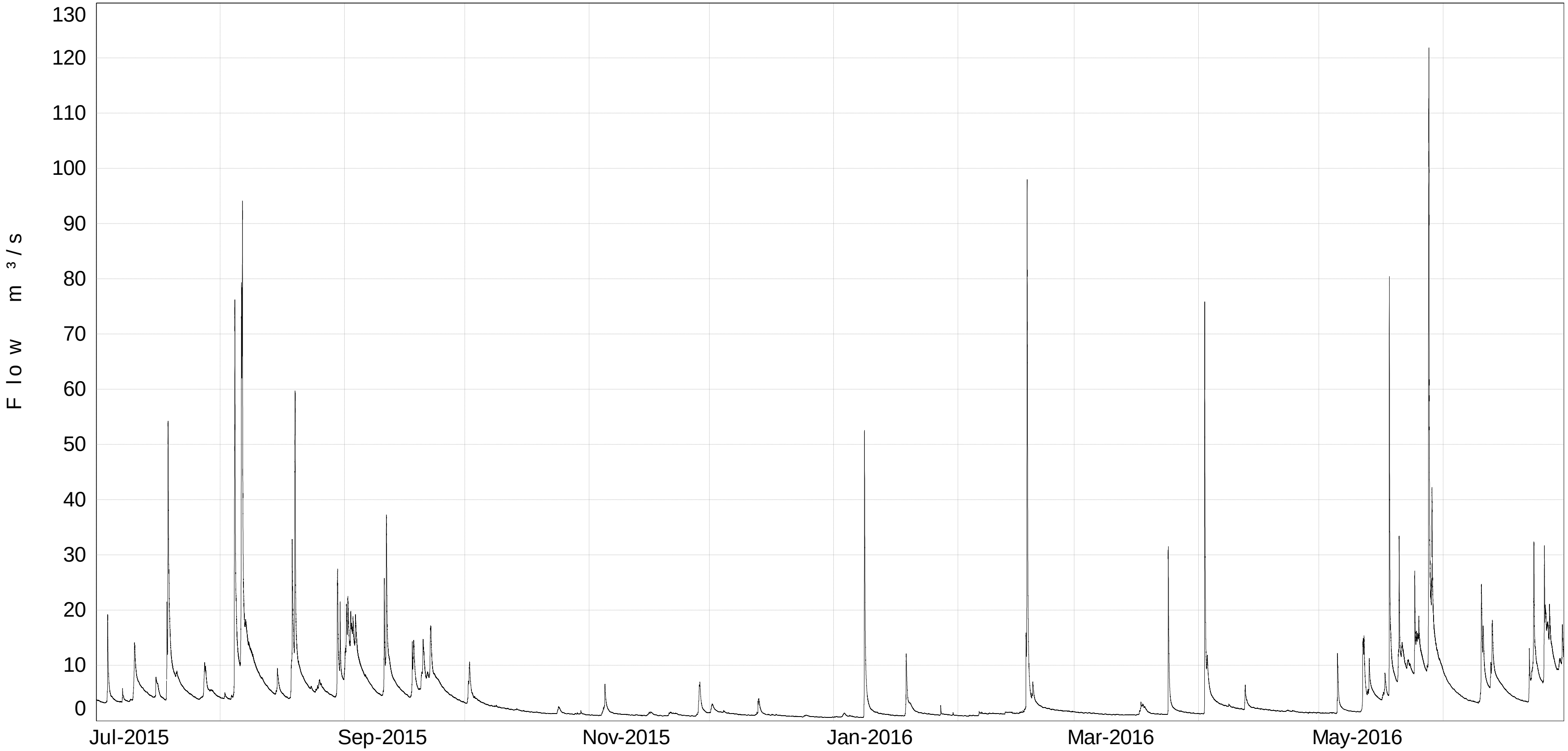

Figure 4 Flow in the Patea River at Skinner Road from July 2015 to June 2016

3. Results

3.1 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.

Table 3 Observations at Lake Rotorangi monitoring sites on each sampling date during 2015-2016

Site	Date	Time	Weather	Wind	Air Temperature	Surface Water Temperature	Appearance	Secchi Disc transparency	Black Disc transparency	Depth at sampling site
Unit		(NZST)			(°C)	(°C)		(m)	(m)	(m)
L2	23.10.15	0925-1015	Overcast, fine	Moderate	17.6	15.2	Turbid, mid-green surface ripple; no debris noted	1.45	1.37	37
	24.02.16	0935-1035	Overcast, fine	Calm	20.1	22.8	Turbid, green; surface flat; no debris noted	2.88	1.80	39
	22.03.16	0905-1020	Clear, fine	Calm	16.7	20.9	Clear, green; surface flat; no debris noted	4.91	2.26	39
	20.06.16	0915-1010	Overcast, fine	Calm	12.5	12.3	Turbid, brown-green; surface flat; debris common	1.80	1.27	40
L3	23.10.15	1050-1150	Overcast, fine	Moderate	20.2	15.6	Turbid, mid-green; surface ripple; no debris noted	2.27	1.78	51
	24.02.16	1135-1350	Overcast, fine	Light	24.5	23.6	Clear, brown; surface ripple; no debris noted	4.06	3.00	53
	22.03.16	1120-1250	Partly cloudy, fine	Calm	27.3	21.2	Clear green; surface flat; no debris noted	3.78	3.10	51
	20.06.16	1050-1150	Overcast, fine	Calm	15.5	12.3	Turbid, brown-green; surface flat; debris common	1.92	1.54	54

[Note: NR = not recorded; NATBD = not able to be determined]

3.1.1 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 2015

Location	Parameter	Unit	Minimum	Maximum	Median	N
L2 surface	Temperature	°C	9.2	23.9	17.2	98
L3 surface	Temperature	°C	9.5	24.6	17.7	99

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 2015-2016 period, are compared with the averages of all data for similar months prior to this year's sampling surveys in Table 5.

Table 5 Temporal changes in temperature (^{o}C) of surface and bottom waters at each Lake Rotorangi site (October 2015 to June 2016)

Sites	L2		L3	
Date	**Surface**	**Bottom**	**Surface**	**Bottom**
October 2015	15.2 (14.7)	9.3 (8.9)	15.6 (14.9)	9.0 (8.7)
February 2016	22.8 (21.8)	9.4 (9.6)	23.6 (22.1)	9.2 (9.4)
March 2016	20.9 (19.4)	9.4 (9.8)	21.2 (19.8)	9.2 (9.6)
June 2016	12.3 (11.2)	9.6 (9.4)	12.3 (11.3)	9.3 (9.5)

Note: *( ) = average monthly temperature for period 1984 to mid-2015*

All surface water temperatures at both sites were within past ranges measured at these sites (Table 4). Temperatures were within 0.5 ˚C to 1.4 ˚C of past monthly average temperatures at site L2 and 0.7 ˚C to 1.5 ˚C at site L3, at the time of all surveys. Bottom water temperatures at both sites were lower than surface water temperatures by 2.7 ˚C to 3.0 ˚C (winter) and 13.4 to 14.4 °C (late summer) but within 0.2 ˚C to 0.4 ˚C of corresponding monthly average temperatures throughout most of the year. These two sites' bottom water temperatures (9.3 °C to 9.6 °C and 9.0 ˚C to 9.3 ˚C) showed a very narrow range (both 0.3 °C), due to minimal mixing through most of the year, while their surface water temperature ranges were much wider (10.5 °C [L2] to 11.3 °C [L3]).

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

Thermal stratification was recorded at sites L2 and L3 at the time of the October 2015 survey (Figure 5), while both summer-autumn surveys illustrated more well-established thermal stratification at these mid and lower lake sites. The location of the thermocline was between 6 and 9 m below the lake surface at both sites. The occurrence of several significant freshes between mid May and the winter June 2016 survey, and cooling of epilimnetic waters, contributed to almost complete destruction of temperature stratification at these sites by the time of the June 2016 survey, although strong dissolved oxygen stratification remained at site L3 at this time (see section 3.1.2), a similar situation to that monitored in many previous years.

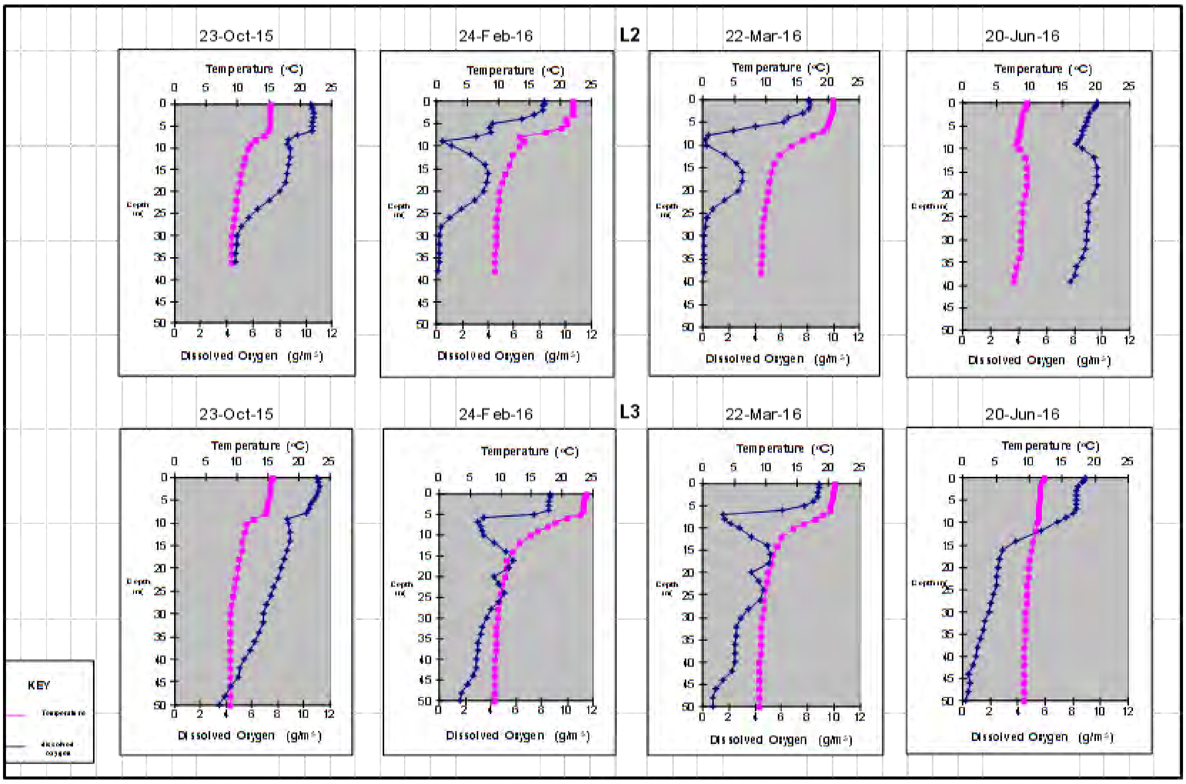

Figure 5 Temperature (°C) and dissolved oxygen (g/m³) profiles for sites L2 and L3

3.1.2 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 2015

Location	Parameter	Unit	Minimum	Maximum	Median	N
L2 surface	Dissolved oxygen	g/m³	6.8	11.1	8.8	98
	Dissolved oxygen saturation	%	68	116	92	98
L3 surface	Dissolved oxygen	g/m³	3.6	10.7	8.8	99
	Dissolved oxygen saturation	%	34	116	95	99

Table 7 Temporal changes in percentage dissolved oxygen saturation in surface and bottom waters at each Lake Rotorangi site (October 2015 to June 2016)

Sites	L2		L3	
Date	Surface	Bottom	Surface	Bottom
October 2015	105 (94)	40 (28)	112 (97)	31 (33)
February 2016	97 (98)	1 (2)	102 (101)	14 (7)
March 2016	90 (92)	1 (4)	100 (93)	6 (7)
June 2016	89 (81)	67 (55)	83 (64)	1 (14)

Note: ( ) = average monthly saturation for period 1984 to mid-2015

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 11% of total saturation or supersaturated with the exception of the winter, partial overturn level which fell to 83% saturation at site L3. 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 2016, as indicated by the decrease in percentage saturation to well below 100% saturation. Spring levels indicated supersaturation (105% to 112%) at both sites.

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 somewhat lesser degree at the time 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 2016 surveys at the mid lake site (L2), while the lower lake site L3 did not record total depletion within the hypolimnion at these times but showed near total depletion below 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, more particularly below depths of 30 metres. 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 m 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 twenty of the previous twenty-two years. Dissolved oxygen levels were below 2 g/m^3 in the lower lake waters of site L3 at the times of the late summer, autumn, and winter surveys beyond 40 m to 45 m in depth (Figure 5). There was little oxygen depletion at site L2 in winter, indicative of complete lake mixing, with levels of more than 7.5 g/m^3 recorded through the lake's depth of 39 metres.

Data from both the temperature and dissolved oxygen profiles at sites L2 and L3 for each of the February/March periods to date 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 deoxygenation 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 the 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 graphically in the trends report attached as Appendix II, but the shortcomings of this parameter should be noted.

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).

3.1.3 Secchi disc transparency/suspended solids

A summary of historical data is provided in Table 8.

Table 8 Statistical summary of physical water quality data from 1990 to June 2015

Location	Parameter	Unit	Minimum	Maximum	Median	N
L2 Surface	Secchi disc transparency	m	0.09	5.23	2.78	98
	Black disc transparency	m	0.09	4.50	2.20	91
	Turbidity	NTU	0.4	240	1.4	84
	Suspended solids	g/m³	<2	170	<2	91
	Conductivity @ 20°C	g/m³	5.4	15.0	11.0	78
L2 Epilimnion	Turbidity	mS/m	0.6	250	1.8	89
	Suspended solids	g/m³	<2	180	2	96
	Conductivity @ 20°C	mS/m	5.3	14.5	11.1	93
L2 Hypolimnion	Turbidity	NTU	1.6	510	5.4	91
	Suspended solids	g/m³	2	340	3	97
	Conductivity @ 20°C	mS/m	5.8	13.5	10.7	95
L3 Surface	Secchi disc transparency	m	0.12	7.0	3.2	99
	Black disc transparency	m	0.12	5.25	2.7	86
	Turbidity	NTU	0.4	250	1.3	87
	Suspended solids	g/m³	<2	170	<2	93
	Conductivity @ 20°C	mS/m	6.2	15.2	10.6	82
L3 Epilimnion	Turbidity	NTU	0.4	250	1.5	89
	Suspended solids	g/m³	<2	170	2	97
	Conductivity @ 20°C	mS/m	6.2	15.0	10.6	93
L3 Hypolimnion	Turbidity	NTU	0.7	780	3.0	91
	Suspended solids	g/m³	<2	500	<2	99
	Conductivity @ 20°C	mS/m	6.2	12.4	10.4	95

Note: Turbidiimeter changed from Hach 2100A to Cyberscan WTW in June 2005.

Data recorded from each site during the 2015-2016 year (Table 9) were within ranges of previous results, with the secchi disc transparency at both sites near to or below median values on all occasions and suspended solids and turbidities above median values on three occasions due to the proximity of preceding freshes.

Table 9 Physical water quality monitoring data for the two Lake Rotorangi sites in the 2015-2016 period

	Sites		L2			L3		
Date	**Parameter**	**Unit**	**S**	**E**	**H**	**S**	**E**	**H**
23.10.15	Secchi disc	m	1.45	-	-	2.27	-	-
	Turbidity	NTU	2.8	3.3	150	2.4	2.6	26
	Suspended solids	g/m³	3	3	150	2	2	12
	Conductivity @ 20°C	mS/m	11.8	10.1	10.2	11.0	10.5	10.1
24.02.16	Secchi disc	m	2.88	-	-	3.00	-	-
	Turbidity	NTU	2.0	2.4	2.6	1.0	1.6	12
	Suspended solids	g/m³	3	<2	<2	<2	<2	4
	Conductivity @ 20°C	mS/m	12.2	12.5	9.4	12.3	12.3	9.9
22.03.16	Secchi disc	m	2.26	-	-	3.10	-	-
	Turbidity	NTU	0.6	0.8	2.3	0.6	0.6	7.5
	Suspended solids	g/m³	<2	<2	3	<2	<2	4
	Conductivity @ 20°C	mS/m	12.0	12.1	9.9	12.0	12.0	9.9
20.06.16	Secchi disc	m	1.27	-	-	1.54	-	-
	Turbidity	NTU	4.7	5.1	8.3	4.0	4.1	8.5
	Suspended solids	g/m³	2	3	3	2	2	<2
	Conductivity @ 20°C	mS/m	9.7	9.7	11.8	9.7	9.9	10.2
Range	Secchi disc	m	1.27-2.88	-	-	1.54-3.10	-	-
	Turbidity	NTU	0.8-4.7	0.8-5.1	2.3-150	0.6-4.0	0.6-4.1	7.5-26
	Suspended solids	g/m³	<2-3	<2-3	<2-150	<2-2	<2-2	<2-12
	Conductivity @ 20°C	mS/m	9.7-12.2	9.7-12.5	9.4-11.8	9.7-12.3	9.9-12.3	9.9-10.2

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

The impacts of relatively recent significant freshes resulted in poor secchi disc clarity at sites L2 and L3 surface waters in spring and winter with elevated turbidity and suspended solids levels. In the hypolimnion, high turbidity and suspended solids levels occurred at both sites in spring, and above median turbidity at site L3 throughout the year. This may have been an effect of the large flood in June 2014.

Similar ranges of secchi disc transparency levels was recorded at site L2 (1.27 to 2.88 m) and site L3 (1.54 to 3.10 m) during the monitoring year. Impacts of river freshes upon lake clarity through the water column at site L2 were more marked in October 2015 and June 2016 due to several freshes preceding these surveys.

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 both of the 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.

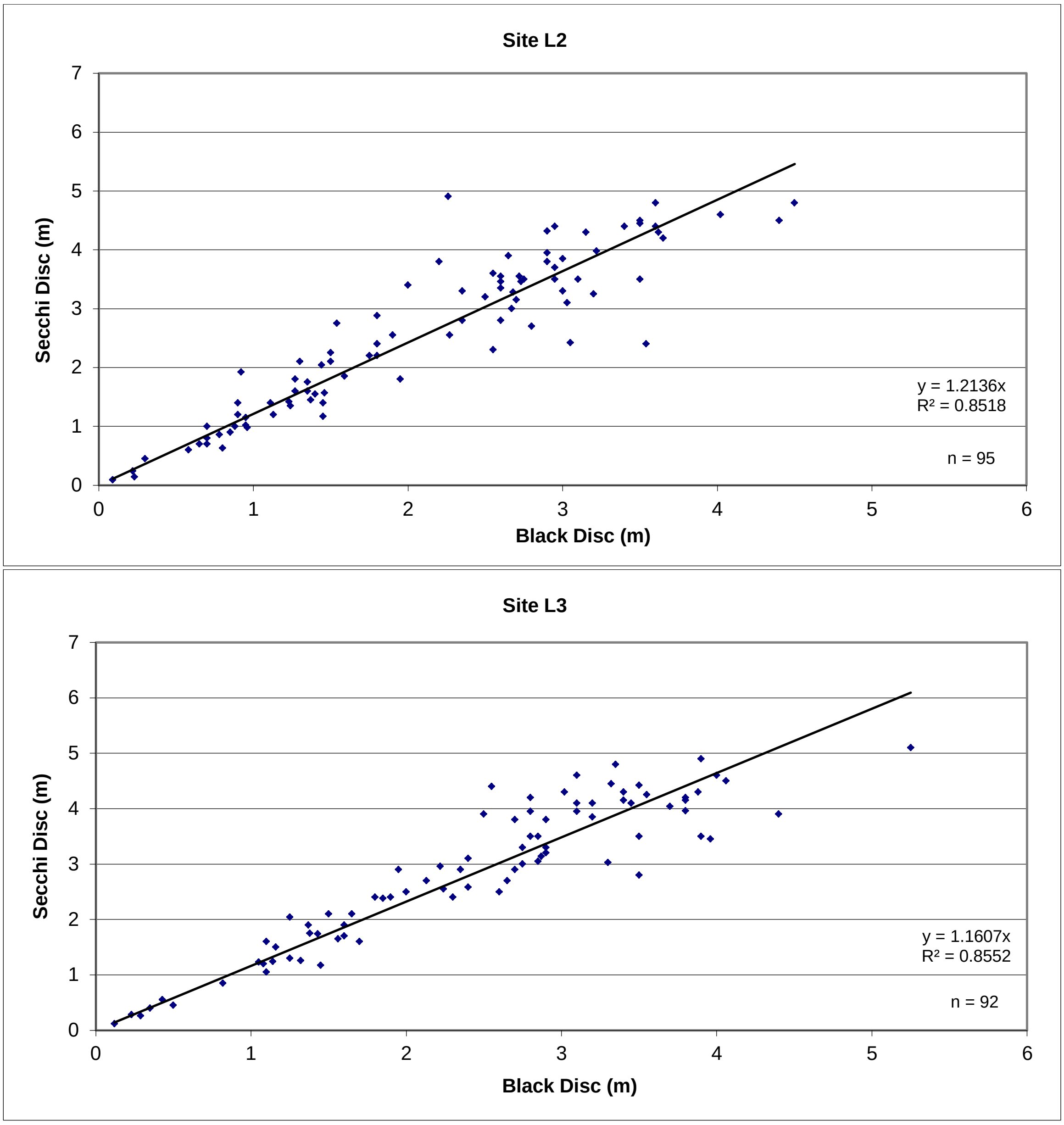

Figure 6 Relationship between secchi and black disc transparency at each sampling site

These trends have continued to be recorded during the most recent monitoring period under a moderate range of clarities. During the 2015-2016 monitoring period, black disc transparency ranges recorded at site L2 (1.27 to 2.88 m) were slightly lower than at site L3 (1.54 to 3.10 m) and did not approach historical maxima (Table 9) as a result of poorer clarity due to the effects of preceding river freshes.

3.1.5 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 10.

Table 10 Statistical summary of chlorophyll-a data from 1990 to June 2015

Location	Parameter	Unit	Minimum	Maximum	Median	Mean	N
L2 photic zone	Chlorophyll-a	mg/m³	<1.0	13.9	2.6	3.2	98
L3 photic zone	Chlorophyll-a	mg/m³	<1.0	13.4	2.2	3.2	98

Results recorded during the monitoring programme are presented in Table 11 and a summary of yearly results in Table 12.

Table 11 Chlorophyll-a concentrations (mg/m3) (including historical monthly means) for the Lake Rotorangi sites

Date	Sites			
	L2		L3	
	Mean (1984-2015)	Result 2015-16	Mean (1984-2015)	Result 2015-16
October 2015	3.5	-	3.9	-
February 2016	3.5	5.0	3.1	3.0
March 2016	3.8	1.7	4.4	4.1
June 2016	1.7	1.7	1.5	1.7
Range: 2015-2016	-	1.7-5.0	-	1.7-4.1
Range: 1984-2015	-	<1-13.9	-	<1-15

Table 12 Summary of past chlorophyll-a concentrations (mg/m3) survey data for the two Lake Rotorangi sites (1984 to 2015)

	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
2013	4	4.2	1.9-7.8	4	5.3	2.4-8.7
2014	4	4.1	<1-4.0	4	5.2	1.1-10.0
2015	4	3.8	<1-5.5	3	3.8	<1-8.2

All chlorophyll-a concentrations measured at the two sites over the 2015-2016 period were within past ranges (Table 10) found by surveys since 1990.

Concentrations at site L2 reduced between the summer and autumn surveys, from well above to well below the historical median seasonal value, and were at median value in winter. Concentrations at site L2 were near to historical median season values for all surveys. No chlorophyll-a analysis was performed on the October 2015 samples.

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 lake in summer and in the lower lake in autumn. All measured concentrations were within previous ranges recorded since 1984 at each site (Table 11 and Table 12). The maximum chlorophyll-a concentration of 5.20 mg/m^3 was measured at lake site L2 during the summer period and this was 2.0 mg/m^3 higher than the concentration found at site L3 in summer.

Mean 2015 values at both sites were within historical values, although toward the maximum at site L3, for the sampling period from 1994 to 2014. The average annual means to July 2014 have been 3.0 mg/m^3 for site L2 (range: 1.2 to 5.3 mg/m^3) and 3.1 mg/m^3 for site L3 (range: 1.3 to 5.3 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).

3.1.5.1 Nutrients

A summary of historical nutrients data is provided in Table 13, with water quality data relating to nutrient species, measured during the monitoring period, summarised for each site in Table 14 to Table 17. The results are discussed in relation to the epilimnion and hypolimnion of the lake.

Table 13 Statistical summary of nutrients data from 1990 to June 2015

Site	Parameter	Unit	Minimum	Maximum	Median	No. of samples
L2 Epilimnion	Dissolved reactive phosphorus	g/m^{3}P	<0.003	0.018	0.005	97
	Total phosphorus	g/m^{3}P	0.006	0.27	0.023	97
	Ammonia nitrogen	g/m^{3}N	<0.003	0.37	0.020	97
	Nitrite	g/m^{3}N	<0.001	0.015	0.007	87
	Nitrate	g/m^{3}N	<0.01	0.99	0.31	89
	Total Kjeldahl nitrogen	g/m^{3}N	<0.01	1.20	0.27	94
	Total nitrogen	g/m^{3}N	0.20	1.65	0.62	93
	pH		6.8	8.6	7.5	89
L2 Hypolimnion	Dissolved reactive phosphorus	g/m^{3}P	<0.003	0.029	0.008	97
	Total phosphorus	g/m^{3}P	0.011	0.46	0.022	97
	Ammonia nitrogen	g/m^{3}N	0.003	0.44	0.075	97
	Nitrite	g/m^{3}N	<0.001	0.022	0.009	87
	Nitrate	g/m^{3}N	0.02	0.93	0.49	91
	Total Kjeldahl nitrogen	g/m^{3}N	<0.01	0.99	0.28	96
	Total nitrogen	g/m^{3}N	0.45	1.72	0.78	96
	pH		6.5	7.4	6.9	90
L3 Epilimnion	Dissolved reactive phosphorus	g/m^{3}P	<0.003	0.023	0.004	97
	Total phosphorus	g/m^{3}P	0.004	0.33	0.018	97
	Ammonia nitrogen	g/m^{3}N	<0.003	0.183	0.011	97
	Nitrite	g/m^{3}N	<0.001	0.020	0.005	87
	Nitrate	g/m^{3}N	<0.01	0.83	0.35	89
	Total Kjeldahl nitrogen	g/m^{3}N	<0.01	1.15	0.26	94
	Total nitrogen	g/m^{3}N	0.19	1.51	0.61	93
	pH		6.6	8.7	7.6	89
L3 Hypolimnion	Dissolved reactive phosphorus	g/m^{3}P	<0.003	0.026	0.006	97
	Total phosphorus	g/m^{3}P	0.005	0.67	0.017	97
	Ammonia nitrogen	g/m^{3}N	<0.003	0.34	0.006	97
	Nitrite	g/m^{3}N	<0.001	0.020	0.001	87
	Nitrate	g/m^{3}N	0.05	1.00	0.57	91
	Total Kjeldahl nitrogen	g/m^{3}N	<0.01	1.63	0.16	96
	Total nitrogen	g/m^{3}N	0.30	2.2	0.76	96
	pH		6.5	7.2	6.8	91

Table 14 Nutrient water quality monitoring data for Lake Rotorangi site L2: Epilimnion (2015-2016)

Parameter		Date			
	Unit	23 Oct 2015	24 Feb 2016	22 Mar 2016	20 June 2016
Sample depth	m	9	4	4	6
Dissolved reactive phosphorus	g/m^{3}P	0.009	<0.003	<0.003	0.008
Total phosphorus	g/m^{3}P	0.028	0.013	0.024	0.036
Ammonia-N	g/m^{3}N	<0.003	0.016	0.024	0.016
Nitrite	g/m^{3}N	0.003	<0.001	0.003	0.018
Nitrate	g/m^{3}N	0.61	0.03	0.13	0.85
TKN	g/m^{3}N	0.10	0.21	0.25	0.03
Total nitrogen	g/m^{3}N	0.71	0.24	0.38	0.90
pH	pH	7.2	7.5	7.4	7.2

Table 15 Nutrient water quality monitoring data for Lake Rotorangi site L2: Hypolimnion (2015-2016)

Parameter		Date			
	Unit	23 Oct 2015	24 Feb 2016	22 Mar 2016	20 June 2016
Sample depth	m	30	20	24	38
Dissolved reactive phosphorus	g/m^3P	0.007	<0.003	0.004	0.009
Total phosphorus	g/m^3P	0.069	0.008	0.015	0.037
Ammonia-N	g/m^3N	<0.003	0.005	0.006	0.105
Nitrite	g/m^3N	0.001	<0.001	0.001	<0.001
Nitrate	g/m^3N	0.87	0.64	0.72	0.86
TKN	g/m^3N	0.39	<0.01	0.08	0.13
Total nitrogen	g/m^3N	1.26	0.59	0.80	0.99
pH	pH	6.8	6.9	6.7	7.2

Table 16 Nutrient water quality monitoring data for Lake Rotorangi site L3: Epilimnion (2015-2016)

Parameter		Date			
	Unit	23 Oct 2015	24 Feb 2016	22 Mar 2016	20 June 2016
Sample Depth	m	6	5	5	6
Dissolved Reactive Phosphorus	g/m^3P	<0.003	<0.003	<0.003	0.009
Total Phosphorus	g/m^3P	0.017	0.022	0.020	0.025
Ammonia-N	g/m^3N	0.009	0.020	0.012	0.003
Nitrite	g/m^3N	0.005	0.002	0.001	<0.001
Nitrate	g/m^3N	0.50	0.05	0.08	0.80
TKN	g/m^3N	0.11	0.19	0.22	0.08
Total nitrogen	g/m^3N	0.62	0.24	0.27	0.88
pH	pH	7.8	7.7	7.7	7.1

Table 17 Nutrient water quality monitoring data for Lake Rotorangi site L3: Hypolimnion (2015-2016)

Parameter	Unit	Date			
		23 Oct 2015	24 Feb 2016	22 Mar 2016	20 June 2016
Sample Depth	m	38	40	36	45
Dissolved Reactive Phosphorus	g/m^3P	0.006	0.006	0.006	0.012
Total Phosphorus	g/m^3P	0.075	0.028	0.022	0.024
Ammonia-N	g/m^3N	<0.003	0.008	0.016	<0.003
Nitrite	g/m^3N	0.002	0.001	0.002	0.001
Nitrate	g/m^3N	0.81	0.76	0.77	0.67
TKN	g/m^3N	0.11	<0.01	0.13	<0.01
Total nitrogen	g/m^3N	0.92	0.70	0.90	0.65
pH		6.9	6.7	6.7	6.7

3.1.5.2 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 (Table 14 and Table 16) on the majority of the monitoring occasions. In general, the lowest concentrations of nutrients, such as TN and TP, were coincident with times when the lake waters were strongly stratified (e.g. summer and autumn, 2016). Total phosphorus concentrations have varied in the past in association with temporal and spatial fluctuations in suspended solids concentrations. These variations were apparent during the monitoring year, but not over a large range as turbidities only varied over a relatively small range (about 4 NTU, Table 9) in the 2015-2016 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 slightly elevated at this time (7.4 to 7.7), consistent with a small increase in mid and lower lake sites' phytoplankton photosynthetic activity (e.g. up to 102% dissolved oxygen saturation of the surface waters, Table 7). 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 7.2) in mid winter 2016 at mid and lower lake sites.

3.1.5.3 Hypolimnion

Anoxic conditions in the hypolimnetic waters during stratification over the summer-autumn period did not result in increases in ammonia-N levels at site L2 (Table 15 and Table 17), as has occurred during all previous years, but elevated ammonia-N level did occur at site L2 in winter. pH levels were consistently close to neutral (6.7 to 7.2 units), often significantly lower (by up to 1.0 pH units) than the pH of the epilimnetic waters and typical of the deeper waters of the hypolimnion particularly during periods of stratification. However, pH levels were more similar (identical at site L2) in winter when the lake was 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 atypical minimal variability as there were only small changes in turbidity caused by suspended sediment settling through the hypolimnetic waters.

3.1.5.4 Bottom of hypolimnion

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

Samples for this purpose have been collected at sites L2 and L3 in February and March of each monitoring year since 1996 during anoxic conditions at site L2 and usually approaching anoxia at site L3. A summary of historical data is provided in Table 18.

Table 18 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 2015

Site	Location			Lower hypolimnion (near bed)			Hypolimnion			
	Parameter	**Unit**	**N**	**Minimum**	**Maximum**	**Median**	**N**	**Minimum**	**Maximum**	**Median**
L2	Dissolved reactive phosphorus	g/m^{3}P	38	<0.003	0.040	0.008	38	<0.003	0.017	0.008
	Total phosphorus	g/m^{3}P	38	0.012	0.28	0.023	38	0.011	0.220	0.020
	Ammonia nitrogen	g/m^{3}N	38	0.015	0.62	0.154	38	0.014	0.297	0.116
	Nitrate + nitrite	g/m^{3}N	33	<0.01	0.70	0.39	35	0.02	0.70	0.44
	Temperature	°C	38	8.1	14.3	9.6	38	8.1	14.4	9.6
	Turbidity	NTU	38	2.4	310	9.4	38	1.6	230	4.2
	Dissolved oxygen	g/m^3	38	0	6.4	0	38	0	7.6	0.1
	pH		29	6.5	7.0	6.8	38	6.5	7.3	6.8
L3	Dissolved reactive phosphorus	g/m^{3}P	37	0.003	0.032	0.007	37	<0.003	0.024	0.006
	Total phosphorus	g/m^{3}P	37	0.008	0.298	0.022	37	0.006	0.082	0.016
	Ammonia nitrogen	g/m^{3}N	37	<0.003	0.111	0.009	37	<0.003	0.064	0.006
	Nitrate + nitrite	g/m^{3}N	33	0.12	0.69	0.56	37	0.17	0.78	0.60
	Temperature	°C	37	7.4	14.7	9.2	37	7.7	14.9	9.2
	Turbidity	NTU	36	0.7	140	9.1	37	0.7	65	1.7
	Dissolved oxygen	g/m^{3}P	37	0	3.5	0.7	37	0	4.8	1.3
	pH		27	6.6	7.0	6.8	37	6.6	7.1	6.8

Historical median data (1996-2015) 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 has been no significant change in phosphorus species at site L2 but some increase at site L3, for total phosphorus, noting that a more marked increase in turbidity has been typical at this site nearer the sediment interface.

The nutrient analytical results from sampling in February 2016 and March 2016 are summarised in Table 19 and may be compared with results of samples collected from higher up the water column within the hypolimnion on the same occasion (Table 15 and Table 17).

Table 19 Nutrient water quality monitoring data for Lake Rotorangi sites L2 and L3: lower hypolimnion (above the lake bed) in the 2015-2016 period

Site		L2		L3	
Parameter	**Unit**	**24 Feb 2016**	**22 Mar 2016**	**24 Feb 2016**	**22 Mar 2016**
Sample depth	M	38	37	50	48
Dissolved reactive phosphorus	g/m^3P	0.005	0.005	0.007	0.008
Total phosphorus	g/m^3P	0.015	0.019	0.079	0.033
Ammonia-N	g/m^3N	0.036	0.067	0.005	0.006
Nitrate + nitrite-N	g/m^3N	0.70	0.61	0.73	0.67
[Dissolved oxygen]	g/m^3	[0.1]	[0.1]	[1.6]	[0.8]
[Turbidity]	NTU	[8.5]	[7.2]	[18]	[4.2]
[pH]		[6.6]	[6.6]	[6.6]	[6.6]
[Total BOD_5]	g/m^3	-	-	-	-

[ ] = 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 not at site L3 (see Figure 5). Both sites showed no significant increases in dissolved reactive phosphorus in the lower hypolimnetic waters near the sediment interface (Table 19) compared with higher in the water column of the hypolimnion (Table 15), but an increase in total phosphorus at site L3 in February 2016 when there was an increase in turbidity. Increases in ammonia nitrogen (0.036 and 0.067 g/m^3N) at site L2 were coincident with reducing conditions deep in the anoxic zone on both survey occasions but there were no increases in ammonia nitrogen at site L3 on either occasion.

Differences in nutrient species between the deeper hypolimnetic waters and waters higher in the hypolimnion were slightly more marked at site L2 during late summer and autumn when more widespread anoxia was recorded. However all nutrient concentrations measured near the lake bed at sites L2 and L3 (Table 19) were within the ranges of historical data (Table 18) measured during summer-autumn anoxic and near anoxic conditions, though nitrate-N at site L2 in February 2016 equalled the highest previous value recorded (in autumn 2004). Total phosphorus increased significantly on one occasion when turbidity indicated additional fine suspended sediment in the water column near the lakebed. Ammonia-N was present below median values under anoxic conditions on both survey occasions at site L2.

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.

3.1.5.5 General

Nutrient data surveyed during the 2015-2016 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 1990-2015 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-five 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).

3.1.5.6 Bacteriological surface water quality

The Council undertakes an extensive freshwater contact recreational bacteriological state of the environment monitoring programme at various bathing sites over summer months elsewhere in the region (see TRC, 2015b). However, in recognition of lake recreational usage (although mainly boating and water-skiing) at site L2 in particular, but also at site L3, bacteriological surface water quality sampling was undertaken at both sites on each of the October 2014, February and March 2015 survey occasions. These results are presented in Table 20 and Table 21.

Table 20 Bacteriological quality monitoring data for Lake Rotorangi site L2: surface water (2014-2015)

Site		Date		
Parameter	**Unit**	**22 Oct 2014**	**24 Feb 2015**	**23 Mar 2015**
Time	NZST	1010	0915	0915
Temperature	˚C	16.9	22.0	19.4
Turbidity	NTU	1.1	0.9	0.8
Faecal coliforms	cfu/100 ml	9	53	5
E.coli	cfu/100 ml	9	53	5

Table 21 Bacteriological water quality monitoring data for Lake Rotorangi site L3: Surface (2014-2015)

Site		**Date**		
Parameter	**Unit**	**22 Oct 2014**	**24 Feb 2015**	**23 Mar 2015**
Time	NZST	1155	1110	1055
Temperature	˚C	18.3	22.6	19.4
Turbidity	NTU	0.7	0.9	1.1
Faecal coliforms	cfu/100 ml	4	<1	3
Ecoli	cfu/100 ml	4	<1	3

Bacteriological water quality was well within the guidelines for contact recreation (MfE, 2003) at both sites on all sampling occasions. Sparse birdlife was noted on the water in the vicinity of sites L2 and L3 and, although minimal recreational usage was recorded on sampling occasions, boating and water-skiing are popular activities at site L2 in particular and swimming also occurs at site L3.

3.2 Biological monitoring

3.2.1 Methods

During the 2015-2016 monitoring period the biological monitoring of Lake Rotorangi involving the Regional Council included:

- lake phytoplankton communities; and
- a macrophyte survey of the lake

The macrophyte survey was performed last in March 2015, when both banks were visually surveyed from a boat. The dominant species was recorded, with the presence of other species noted and mapped.

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 2015, February 2016, March 2016, and June 2016. 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 magnification.

No benthic macroinvertebrate sampling was undertaken from the lakebed at sites L2 and L3 at the time of the spring survey as this long-term component of the monitoring programme in future will be performed at less frequent intervals.

3.2.2 Results

3.2.2.1 Lake phytoplankton communities

Phytoplankton samples were collected from Lake Rotorangi on 23 October 2015, and 24 February, 22 March, and 20 June 2016. These samples were taken from within the photic zone (surface waters) of site L2 and L3. Table 22 and Table 23 list the phytoplankton taxa found at each site during the past year. Taxa data from previous years are listed in previous Annual Reports, but particularly in TRC, 2009.

3.2.2.1.1 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 22 Phytoplankton found at site L2 in Lake Rotorangi during the 2015-2016 period

Date	23 October 2015	24 February 2016	22 March 2016	20 June 2016
GREEN ALGAE				
Unidentified (unicellular)		P	P	P
Ankistrodesmus		P		
Selenastrum		P		
Micractinium		P		
Eudorina	P			
CYANOBACTERIA				
Anabaena		P		
Chroccus		P	P	
Microcystis			P	
DIATOMS				
Synedra	P	P	P	
Navicula	P		P	
Cymbella		P		
Fragilaria				P
GOLDEN BROWNS				
Mallomonas		P		
Synura	P			
EUGLENOIDS				
Trachelomonas	A	P		P
CRYPTOPHYTES				
Cryptomonas	A	A		
TOTAL	6	11	5	3

P – Present
A - Abundant

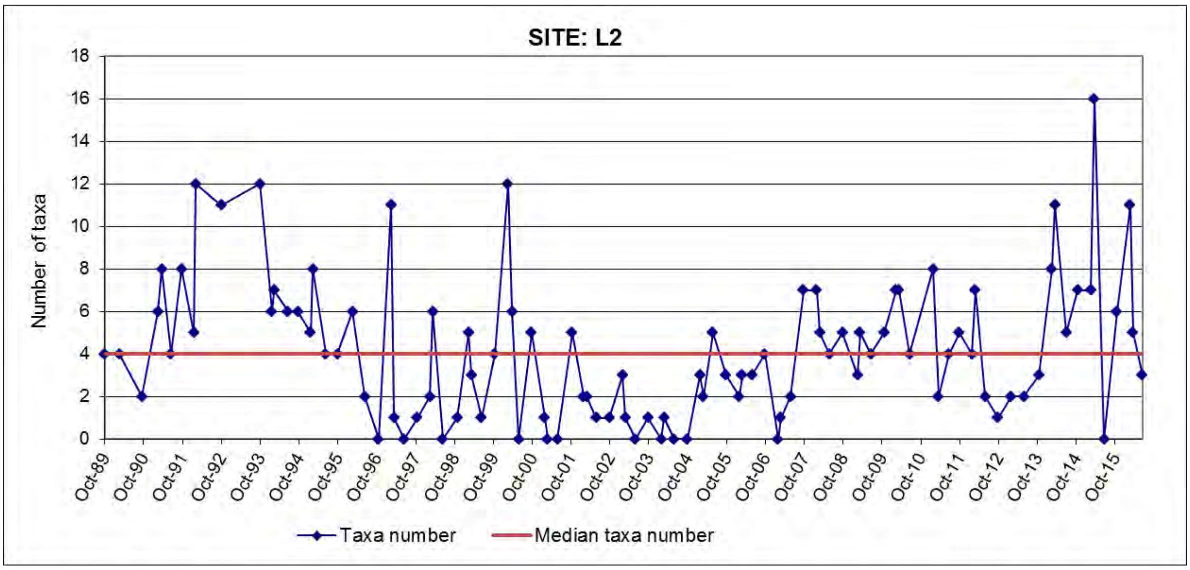

Figure 7 Number of phytoplankton taxa recorded at site L2 in Lake Rotorangi since monitoring began in 1989

A wide range of numbers of taxa (0 to 11) was recorded at site L2 during the 2015-2016 monitoring period, with numbers above the historical median richness (4 taxa) on three occasions; reaching a maximum richness (11 taxa) after a lengthy dry late summer period. Chlorophyll-a concentrations had a moderate range (1.7 to 5.0 mg/m^3 (Table 11)), with the highest level (5.0 mg/m^3) coincident with maximum richness during late summer. Only one individual taxon (golden brown alga *Synedra*) was present on three survey occasions and two taxa (euglinoid *Trachelomonas* in spring, and cryptophyte *Cryptomonas* in spring and winter) were recorded as abundant.

3.2.2.1.2 Site L3

A moderate range of numbers of taxa was found at L3 during the 2015-2016 monitoring period, similar to, or above, the historical median (3 taxa) richness. Seven to eight taxa were present on the late summer and autumn sampling occasions (Figure 8), coincident with chlorophyll-a concentrations of a relatively narrow range (3.7 to 4.1 mg/m^3), whereas lower richness in winter was coincident with a chlorophyll-a concentration of 1.7 mg/m^3).

Table 23 Phytoplankton found at site L3 in Lake Rotorangi in the 2015-2016 period

Date	23 Oct 2015	24 Feb 2015	22 Mar 2016	20 Jun 2016
GREEN ALGAE				
Unidentified (unicellular)		P	P	P
Staurastrum			P	
Pandonna	P			
Eudorina	P			
Dictyosphaerium	P			
Selenastrum		P		
CYANOBACTERIA				
Microcystis			P	
DIATOMS				
Asterionella			P	
Synedra		P		
Cymbella			P	
Gomphonema		P		
Fragilaria			P	
GOLDEN BROWNS				
Dinobryon		P	A	
Mallomonas		P		
EUGLINOIDS				
Trachelomonas	A			P
CRYPTOPHYTES				
Cryptomonas	P	P	P	
TOTAL	5	7	8	2

P – Present
A – Abundant

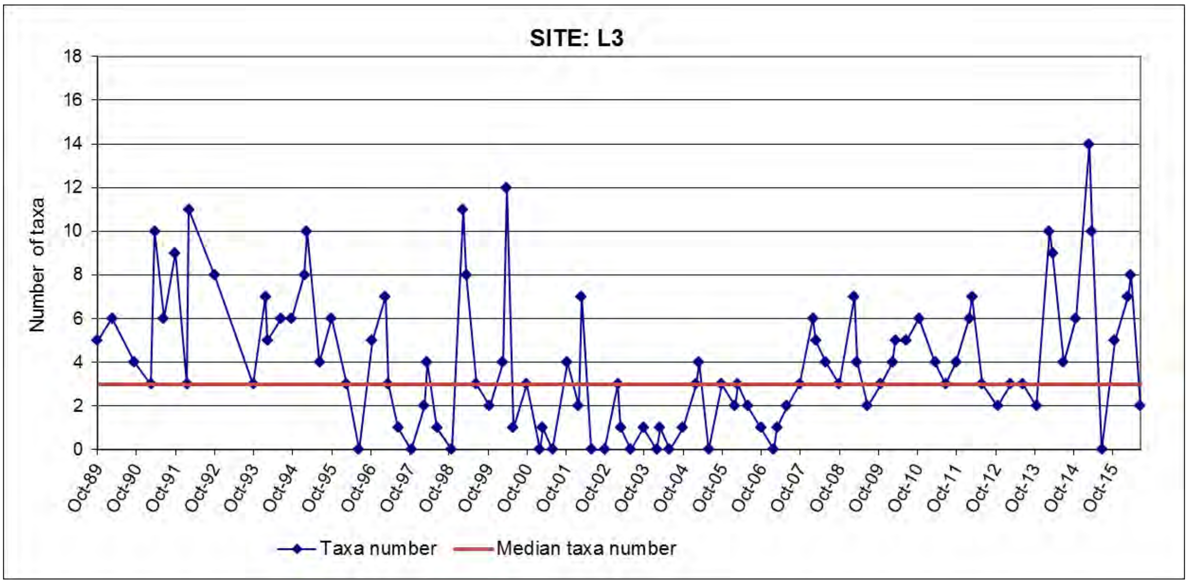

Figure 8 Number of taxa recorded at site L3 in Lake Rotorangi since monitoring began in 1989

One individual taxon was present on three occasions, and two taxa (euglinoid *Trachelomonas* and golden brown alga *Dinobryon*) were abundant on one occasion at the time of the spring and late summer-autumn surveys, respectively.

3.2.2.1.3 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, 2014a)].

In summary, low to moderate taxonomic richnesses was found at both sites throughout the 2015-2016 monitoring year with only three algal taxa, each on one occasion, found in abundance at either site. Taxa richnesses on all survey occasions were similar to or up to seven more than the running median 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 (e.g. late summer/autumn) and these conditions may be confined to very limited periods.

3.2.2.2 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 until the October 2013 survey using an Ekman dredge. No faunal samples were collected in October 2015 as the frequency of monitoring will be reduced in future. The macroinvertebrate taxa found over the period to October 2013 in the lake benthos are summarised in Table 24.

Table 24 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	L2	L3	L2	L3	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		October 2002		October 2003		October 2004		October 2005		October 2006		October 2007		October 2008		October 2009		October 2010		October 2011		October 2012		October 2013	
ANNELIDA Oligochaeta *Branchiura*	XA -	C -	C -	A -	A -	XA -	XA -	XA -	C -	C -	XA -	A -	XA -	C -	VA -	VA -	VA -	A -	XA -	A -	A -	C -	C -	R -	A -	A -	XA -	R -	A R	A -	A -	A -	A -	A R	C R	A -	C -	C -	A -	A -	VA -	A -	- -	- -
MOLLUSCA *Potamopyrgus* *Physa*	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	R R	- -	- -	- -	- -	- -	- -	- -	- -	- -	R -	R -	- -	- -	- -	- -	R -	- -	- -	R -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
CRUSTACEA Copepoda Cladocera Ostracoda	R R C	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	R R R	- - -	R R R	- - -	- R C	- - -	- - -	- - -	- - C	- - -	R - C	- - -	- - -	- - -	- - R	- - -	- - -	- - R	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - R	- - R	- - C	- - -
DIPTERA Orthocladiinae Tanypodinae *C.zealandicus*	- - R	- -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - A	- - R	- - -	- - R	- - --	- - --	- - C	- - -	- - R	- - R	- - R	- - --	- - --	- - --	- - --	- - -	- - --	- - --	- - --	- - --	- - --	- - --	- - R	- -- R	- - -	R 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	3	2	4	1	2	2	5	1	1	3	1	1	1	2	2	1	1	1	2	2	2	4	2	0

[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 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 not found at either site in October 2013; an unusual feature of the survey. Ostracod seed shrimps, found at site L2 by the recent survey, may also be common inhabitants of fine sediments. Amongst the midges, the 'blood-worm' (*Chironomus zealandicus*) is tolerant of very low dissolved oxygen conditions and was present at site L2 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.

3.2.2.3 Aquatic macrophyte survey

The latest survey of the aquatic macrophytes in Lake Rotorangi was performed on 25 March 2015. Surveys are now undertaken as a requirement of consent 0489-2, which requires that surveys be undertaken every three years (commencing in 2012). Results of this survey are presented for reference purposes in Figure 9 and Figure 10 and discussed beneath.

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). Since then, *E. densa* has dominated the lake in most previous surveys, with the exception of the 2005 and 2008 surveys, when *Lagarosiphon major* was dominant. *E. densa* has always dominated the upper end of the lake. The currently reported survey recorded a distribution similar to that recorded in 2012, with *E. densa* being dominant throughout most of the lake, with some smaller areas dominated by *L. major* and *Ceratophyllum demersum* (Figure 9 and **Photo 1**).

Photo 1 A dense bed of *Ceratophyllum demersum.*
(Photo supplied by NIWA.)

The macrophyte survey undertaken in 2012 was the first to document *C. demersum* in Lake Rotorangi. Since this survey, when *C. demersum* was only dominant on the true left bank downstream of the Hawera water ski club rooms, its distribution has increased markedly, as predicted in a report prepared by NIWA[1]. Considering this rate of spread, it is likely that the next macrophyte survey, scheduled for 2018, will find *C. demersum* dominating the lake. *Potamogeton crispus* and *Ottelia ovalifolia* were not recorded as dominant in the current survey despite being found as dominant in some areas during the 2008 survey. *L. major* was dominant in two areas, one closer to the Patea Dam, the other closer to the head of the lake.

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

E. densa, *L. major* and *C. demersum* are introduced aquatic weeds which are listed in the Pest Plant Accord[2], and are thereby considered an 'unwanted organism'. This means that it is illegal to sell, propagate or distribute these plants in New Zealand. *E. densa* and *L. major* are also classified as 'surveillance plants' in the Pest Management Strategy for Taranaki: Plants. All three species are distributed throughout the North Island, and *C. demersum* especially can have significant impacts on hydroelectric schemes. However, Trustpower commissioned NIWA 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.

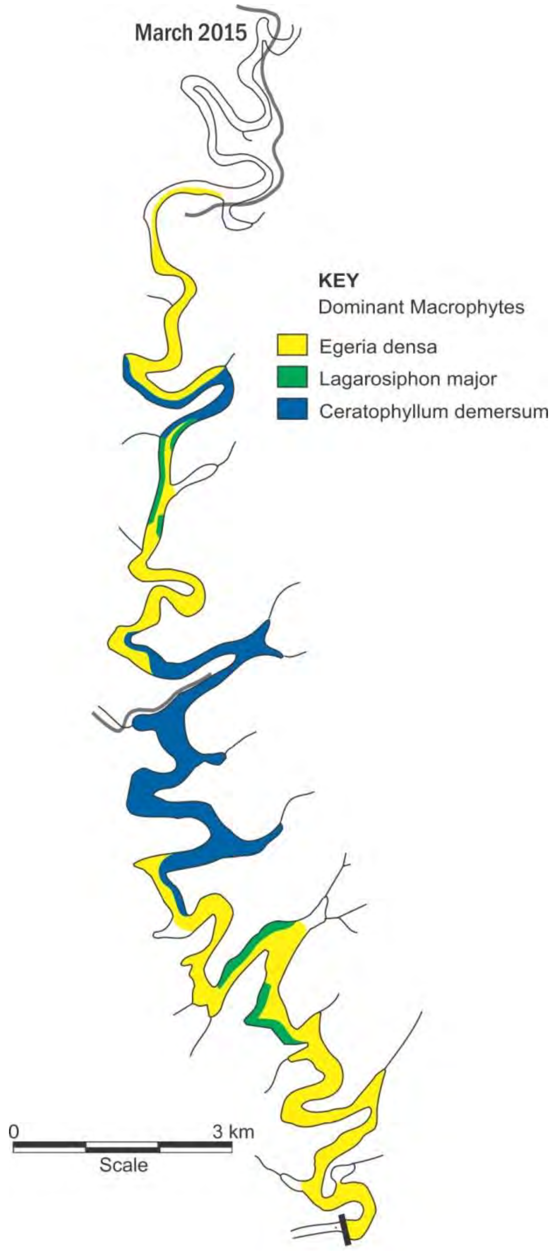

Figure 9 Dominant macrophytes in Lake Rotorangi, 2015

E. densa tends to thrive in turbid and enriched waters of lakes, where as *L. major* is more common in clear water lakes of low fertility. It is interesting to note that the areas where *L. major* typically dominates 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* increased slightly in 2015 (when compared to the 2012 survey), which may reflect the lesser number of floods in what was a particularly dry year, likely causing an improvement in clarity in the lake.

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

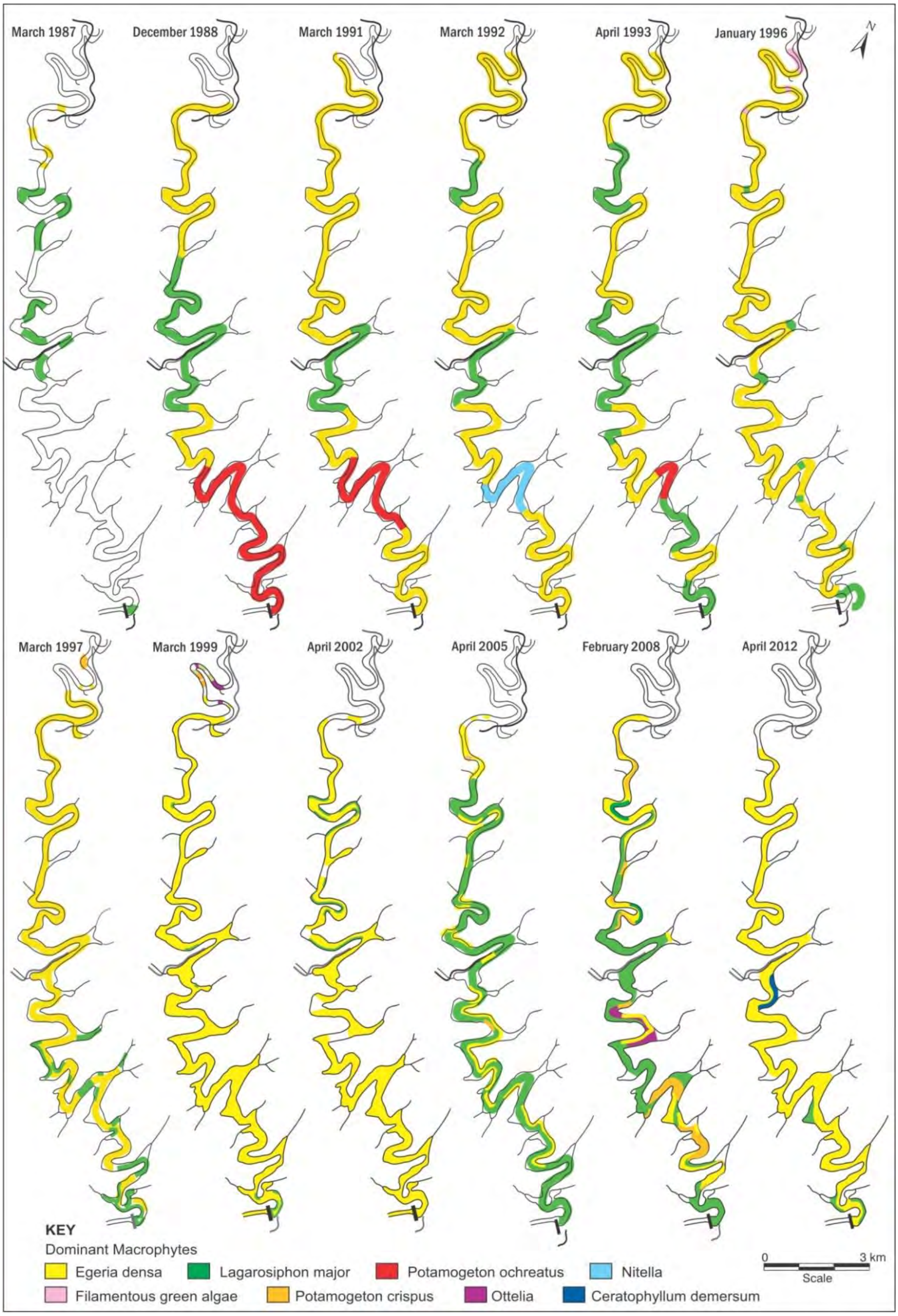

Figure 10 Dominant macrophytes in Lake Rotorangi from March 1987 to April 2012

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 in some areas this has begun to change, with *C. demersum* observed growing in areas as deep as 8 metres. This species is known to grow taller and in deeper water than *E. densa* and *L. major,* and therefore may be able to colonise more of the lake bed.

A summary of the aquatic macrophyte species found in Lake Rotorangi by the summer – autumn surveys performed between 1986 and 2015 is presented in Table 25.

Table 25 Aquatic macrophytes recorded in Lake Rotorangi between 1986 and 2015

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	Mar-15
Aponogeton distachyon	✓	✓												
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 pectinatus	✓	✓												
Filamentous green algae				✓	✓	✓	✓		✓	✓	✓		✓	✓

*Recorded by NIWA in April 2012

A total of 16 aquatic macrophytes has been recorded from Lake Rotorangi over the 29 years of the survey period. Two macrophytes (*E. densa* and *L. major*) have been recorded on all survey occasions. Another species frequently recorded is *P. crispus*, with this species even dominating parts of the lake in 2008. However, in the current survey, this species was only noted at the very head of the lake, and not in abundance. Also during this survey, it was noted that the rudd (*Scardinius erythrophthalmus*) population appeared even more abundant, with large schools noted whenever the boat slowed. A study undertaken in 2002[3] found that rudd, an omnivorous fish, found that of nine macrophytes tested, rudd preferred eating *Potamogeton ochreatus* over *E. densa* and *L. major*, while *C. demersum* was least preferred. Although *P. crispus* was not included in this study, its similar appearance to *P. ochreatus* may indicate that it would also be preferentially eaten by rudd (an omnivorous fish), and this may explain its reduced abundance in Lake Rotorangi in recent years.

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[3] Lake, M.D., Hicks, B.J., Wells, R.D.S. & Dugdale T.M. 2002. Consumption of submerged aquatic macrophytes by rudd (*Scardinius erythrophthalmus* L.) in New Zealand. Hydrobiologia 470: pgs 13–22.

A survey undertaken by NIWA in 2012 recorded four macrophyte species not previously recorded in the lake. It is unlikely that 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 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. In response to the proliferation of this high-risk species, the Council intensified biosecurity advocacy and education under the 'Check, Clean, Dry' programme that it runs in conjunction with the Ministry of Primary Industries and the Department of Conservation.

In summer 2015-2016, larger signs were erected at the three boat entrances to Lake Rotorangi, at Mangamingi, Tangahoe and the Dam, and new signs specifically about *C. demersum*, or hornwort, were added (Photo 2). Clubs and organizations were visited, freshwater events attended, and media releases made to raise awareness about freshwater pests. A survey of water users indicated that, while there was a high awareness around freshwater pests, there was a lack of knowledge about *C. demersum*. This will be addressed next summer.

Photo 2 Pest fish and plants sign at Tangahoe boat ramp, 12 January 2016

4. Conclusions

4.1 Discussion of 2015-2016 programme

4.1.1 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 almost totally oxygen depleted hypolimnetic water recorded at site L3 (i.e. during February-March 2016). Normal lake overturn was complete at site L2 but only partially complete at site L3 in mid-winter (June 2016). These conditions generally 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), although spring 2013 records at site L3 suggest that mixing may never be complete nearer the lake bed.

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 trend evaluation for the period 1990 to 2014 (Appendix II) which was carried out by the Council. 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 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 minor changes in total phosphorus levels (usually coincident with increased turbidity due to fine sediment).

Variability in levels of turbidity and suspended solids concentrations at the times of the four 2015-2016 surveys were related to the recency of river freshes. Freshes prior to the spring 2015 and winter (2016) surveys 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 generally were not excessive at mid and lower lake sites and 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 Council for the 25 year period 1990-2015 (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 (0.01 $\pm$ 0.01 TLI units per year). However, given the tendency for the reservoir water to contain elevated (fine) silt levels, which artificially elevate the trophic index, the trophic category is more appropriately mesotrophic. This is further confirmed by mesotrophic chlorophyll-a level. The analysis also notes significant increase in the average concentration of chlorophyll-a, but not the other key variables (secchi disc visibility, total phosphorus, and total nitrogen). Other variables showing significant temporal trends were dissolved oxygen, temperature and nitrate, all increasing.

4.1.2 Biology

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

The autumn 2015 macrophyte survey identified the oxygen weed *Egeria densa* as the dominant macrophyte throughout the majority of the lake. Only two other species were recorded as dominant in areas, being *Lagarosiphon major* and *Ceratophyllum demersum* (hornwort), the latter having markedly increased in distribution. This is the second record of hornwort in Lake Rotorangi. In addition to those species recorded by the Council, an additional three new species were recorded by NIWA in April 2012 when commissioned by TrustPower to assess the hornwort community within the lake. 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. The next survey is due to be performed in the 2017-2018 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 their responsibilities for preventing the transportation of aquatic plants between the waterways. These were updated during the 2015-2016 period, with particular reference to hornwort.

A very sparse macroinvertebrate fauna, but with an absence of oligochaete (tubificids) worms, has been recorded from the fine sediments of the lake bed between 1996-2013 at the mid lake site and at the lower lake site consistent with periodic occurrences of anoxic or oxygen depleted conditions recorded at these two relatively deep sites. This component of the programme has been decreased in frequency for future monitoring requirements.

4.2 2014-2015 Report's recommendations

The recommendation contained in the 2014-2015 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 Council's 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 2017-2018), and that the requisite macrophyte and benthic macroinvertebrate surveys be components of the 2017-2018 programme.

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 including the triennial performance of the macrophyte survey. 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.

4.3 Alterations to monitoring programme for 2016-2017

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 2017-2018 period. No alterations are required to the 2016-2017 programme, and it is noted that the designated macrophyte survey will next be undertaken in early 2018 and the benthic macroinvertebrate survey in spring 2017.

A recommendation to this effect is attached to this report.

5. Recommendation

The following recommendation is based on the results of the 2015-2016 water quality and biological monitoring programme and the contractual requirements of the recently renewed consents held by Trustpower for the Patea Hydro Electric Power Scheme on Lake Rotorangi:

1. THAT the Lake Rotorangi physicochemical and biological water quality monitoring programme continue on an annual basis as a component of the Council's 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 2017-2018), and that the requisite macrophyte and benthic macroinvertebrate surveys be components of the 2017-2018 programme.

6. Acknowledgements

The programme Job Manager was Bart Jansma (Scientific Officer). The principal author of the Annual Report was James Kitto (Science Advisor). Statistical trend analyses were provided by Fiza Hafiz and Alex Connolly (Scientific Officers). Field lake sampling surveys were performed by Bart Jansma assisted by boatpersons Brent Nicol and Michelle Hitchcock. Hydrological data was provided by Fiona Jansma (Scientific Officer). All water quality analytical work was performed by the Taranaki Regional Council ISO-9000 accredited laboratory under the supervision of John Williams. Phytoplankton analyses were performed by Darin Sutherland (Scientific Officer) in the Council's biology laboratory.

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)
conductivity	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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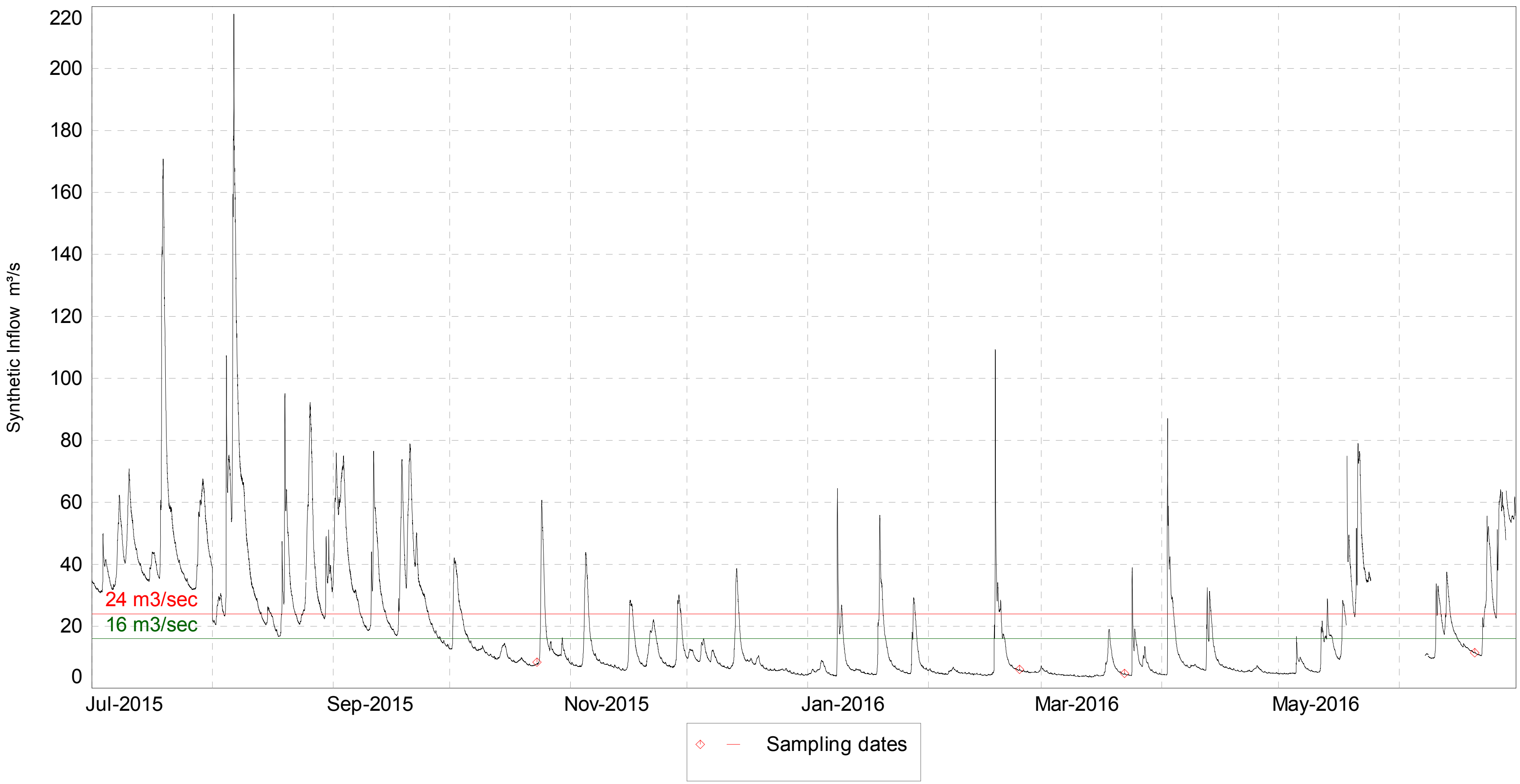
Appendix I

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 2015 to 30 June 2016

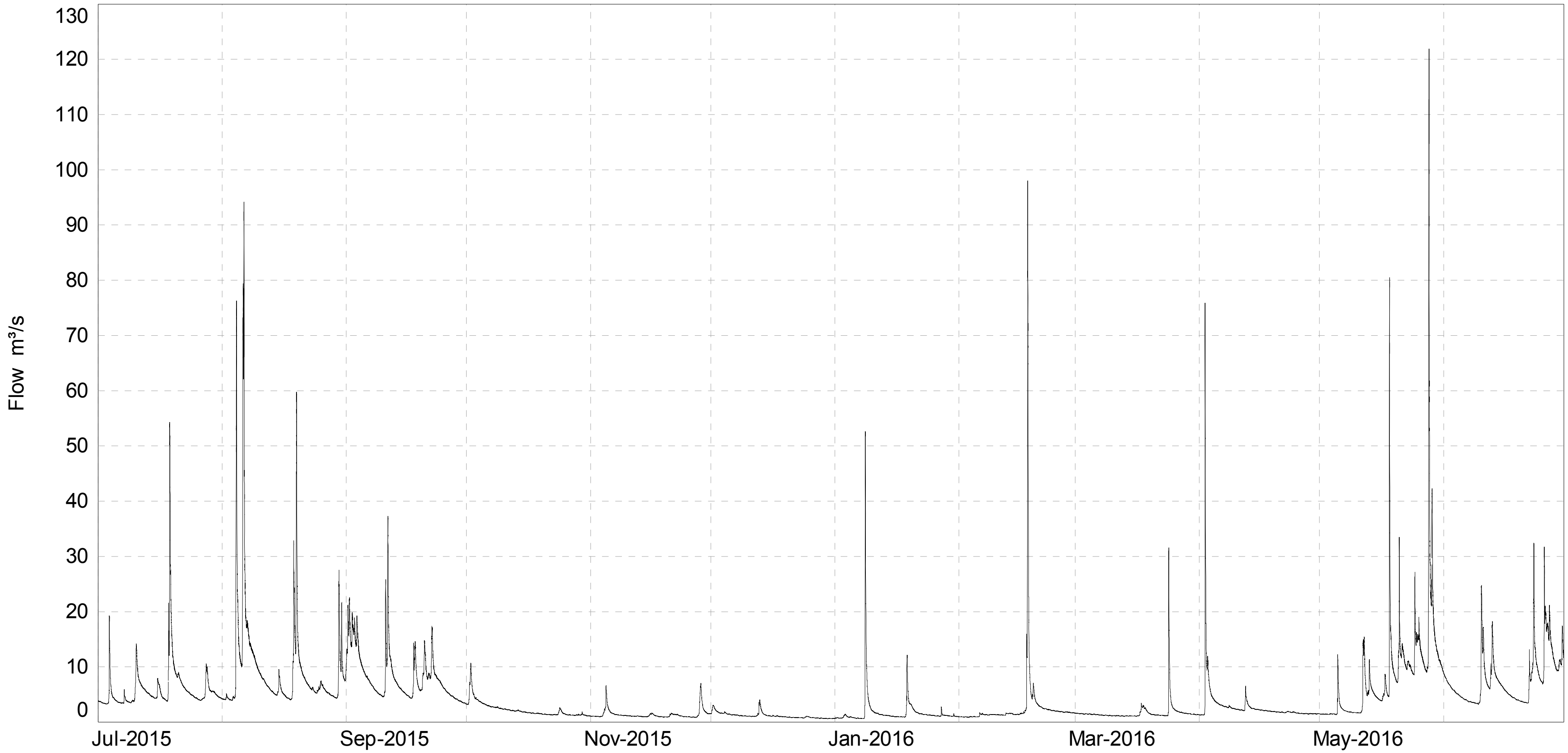


Synthetic inflow at Lake Rotorangi for the period 1 July 2015 to 30 June 2016

Source is R:\PROCESSING-FILE\WATER TAKES & DISCHARGES.hts
Synthetic Inflow (m3/sec) at Patea Dam
From 1-Jul-2015 00:00:00 to 30-Jun-2016 24:00:00
24 hour periods beginning at midnight each day.

Daily means Years 2015-2016 Synthetic Inflow(m3/sec) at Patea Dam

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
1	33.666	21.421	56.051	16.470	7.795	11.239	4.733	5.819	6.163	4.411	4.728	?	
2	31.823	27.441	60.335	39.049	7.326	11.531	5.674	5.196	5.319	30.472	4.694	?	
3	33.894	26.892	69.837	27.883	7.124	9.178	5.731	4.923	4.762	32.334	4.715	?	
4	40.461	51.094	50.600	21.129	22.306	11.428	7.997	4.727	4.571	18.019	4.841	?	
5	35.558	66.922	36.674	16.761	30.924	13.741	6.482	4.556	4.429	10.485	8.100	?	
6	32.591	146.613	31.304	14.364	14.279	9.468	4.748	5.427	4.307	8.230	9.220	?	
7	43.582	99.628	27.245	12.826	10.285	11.145	4.239	6.212	4.200	7.134	7.665	?	
8	54.037	68.511	22.372	12.434	8.749	9.382	19.144	5.380	4.191	7.046	6.163	?	
9	42.617	55.104	19.603	12.784	8.000	7.700	21.762	4.935	4.049	7.333	5.613	9.768	
10	61.285	40.017	23.175	11.289	7.630	6.962	12.497	4.845	3.855	6.615	5.307	21.017	
11	53.020	31.924	53.551	10.574	7.223	6.565	7.051	4.768	3.885	6.101	7.011	27.048	
12	44.175	27.851	44.825	9.906	6.939	7.304	5.918	4.539	3.935	14.567	17.541	19.786	
13	39.460	23.749	29.685	9.834	6.365	26.545	5.979	4.552	3.777	23.451	20.108	31.130	
14	36.480	21.206	24.009	13.049	5.971	20.816	5.622	4.371	3.872	13.121	16.730	21.619	
15	35.464	24.530	20.652	12.406	7.206	10.758	5.005	4.232	4.147	8.710	12.232	17.441	
16	41.856	22.272	18.554	9.500	25.493	8.883	4.691	4.299	4.085	7.337	9.780	15.016	
17	40.192	18.278	19.273	8.677	17.173	8.890	4.575	6.038	6.477	6.740	21.976	?	
18	51.577	21.578	53.531	8.678	9.833	8.248	5.194	41.589	15.169	6.364	?	13.035	
19	137.114	49.541	41.675	9.332	7.703	9.196	34.401	24.254	9.171	6.013	39.453	12.095	
20	69.811	48.260	64.677	8.264	8.320	6.988	23.319	15.757	6.034	5.656	26.834	11.384	
21	55.608	29.314	52.717	7.533	16.516	6.181	12.507	9.229	5.016	5.475	63.206	10.811	
22	46.177	23.494	42.395	7.362	19.954	5.881	8.354	7.076	4.522	5.352	49.246	17.348	
23	40.409	21.637	32.793	7.959	13.163	5.879	6.770	6.242	4.259	5.604	36.020	38.738	
24	36.911	25.719	29.218	37.320	9.219	5.775	5.951	5.796	13.836	5.909	?	40.924	
25	34.470	57.646	23.884	27.822	7.836	6.007	5.395	5.494	14.616	6.775	?	25.143	
26	32.418	73.924	20.102	13.936	7.166	5.905	4.959	5.270	7.959	5.880	?	47.472	
27	32.737	37.240	17.636	12.370	7.106	5.247	8.304	5.111	10.412	5.191	?	59.715	
28	51.714	27.332	15.881	10.759	20.304	4.792	24.070	5.207	7.554	4.963	?	?	
29	63.684	23.418	14.634	11.981	21.807	4.534	11.256	5.636	5.647	4.880	?	54.949	
30	51.965	38.362	13.512	11.686	11.476	4.401	7.026		4.957	4.831	?	?	
31	41.831	35.629		8.914		4.315	6.144		4.601		?		
Min	31.823	18.278	13.512	7.362	5.971	4.315	4.239	4.232	3.777	4.411	4.694	9.768	3.777
Mean	46.664	41.502	34.347	14.285	12.040	8.867	9.532	7.637	6.122	9.500	17.326	26.023	19.393
Max	137.114	146.613	69.837	39.049	30.924	26.545	34.401	41.589	15.169	32.334	63.206	59.715	146.613

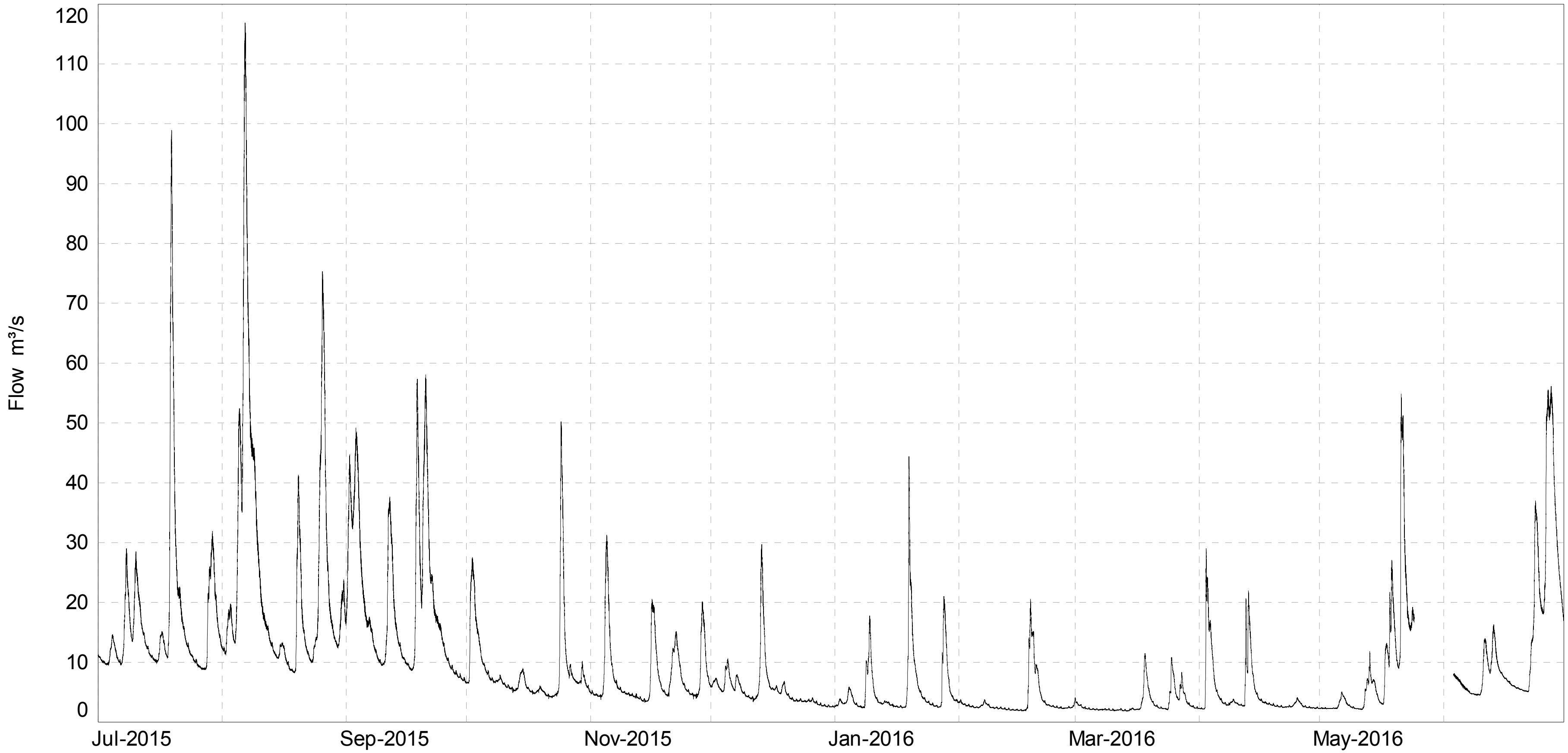


Flow in the Patea River at Skinner Road from July 2015 to June 2016

Source is R:\ARCHIVES\HYDRO-ARCHIVES.HTS
Flow (m³/sec) at Patea at Skinner Rd
From 1-Jul-2015 00:00:00 to 30-Jun-2016 24:00:00
24 hour periods beginning at midnight each day.

Daily means Years 2015-2016 Flow(m³/sec) at Patea at Skinner Rd

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
1	3.695	4.146	16.601	4.474	1.069	2.402	0.750	0.956	1.595	1.314	1.448	8.056	
2	3.406	4.385	16.168	6.600	1.030	2.017	0.723	0.927	1.525	15.128	1.433	6.714	
3	5.830	4.176	15.964	4.184	1.018	1.640	1.183	0.928	1.469	7.603	1.441	5.780	
4	5.523	23.942	11.457	3.655	2.775	1.643	0.928	0.979	1.456	4.274	1.458	5.073	
5	3.909	12.177	9.015	3.266	2.621	1.437	0.838	0.957	1.410	3.477	4.175	4.507	
6	3.527	41.808	7.736	2.957	1.571	1.327	0.711	1.423	1.339	3.059	2.682	4.044	
7	4.026	16.171	6.552	2.759	1.349	1.269	0.660	1.354	1.269	2.801	2.044	3.707	
8	3.705	12.953	5.583	2.673	1.248	1.154	11.540	1.318	1.230	2.734	1.830	3.530	
9	3.726	10.632	4.937	2.476	1.185	1.114	4.046	1.368	1.177	2.477	1.737	3.395	
10	8.678	8.734	8.200	2.345	1.143	1.064	1.987	1.333	1.146	2.308	1.679	12.666	
11	7.251	7.487	16.907	2.222	1.070	1.034	1.594	1.303	1.156	2.186	4.022	8.755	
12	6.002	6.383	9.434	2.085	1.078	1.208	1.362	1.373	1.110	3.567	8.568	7.137	
13	5.232	5.524	7.184	2.045	1.024	2.723	1.235	1.566	1.102	2.922	6.882	11.819	
14	4.635	5.066	6.091	1.960	0.989	1.364	1.154	1.467	1.108	2.437	5.383	7.748	
15	4.987	6.842	5.331	1.812	1.179	1.146	1.049	1.394	1.104	2.278	4.375	6.619	
16	5.912	4.949	4.701	1.709	1.441	1.097	0.992	1.519	1.118	2.171	4.114	5.653	
17	4.226	4.302	6.241	1.621	1.101	1.072	0.954	3.628	2.305	2.082	6.101	4.927	
18	13.588	9.716	9.763	1.580	0.983	1.007	1.667	23.843	2.444	1.996	17.799	4.405	
19	16.656	23.271	5.943	1.508	0.924	0.959	4.950	5.078	1.607	1.909	9.520	3.992	
20	8.800	10.622	10.609	1.410	1.056	0.889	2.541	3.411	1.345	1.833	10.655	3.734	
21	7.830	8.078	8.289	1.358	1.466	0.846	1.748	2.725	1.276	1.783	13.382	3.541	
22	6.305	6.719	11.812	1.336	1.346	0.826	1.484	2.414	1.223	1.761	10.555	6.946	
23	5.463	5.971	8.241	1.374	1.119	0.787	1.374	2.232	1.170	1.848	10.323	14.712	
24	4.863	5.441	7.181	2.126	1.004	0.855	1.279	2.080	7.887	1.790	11.492	9.681	
25	4.351	6.541	6.036	1.488	0.950	0.943	1.193	1.972	2.638	1.636	15.419	7.390	
26	4.009	6.067	5.229	1.318	0.901	0.799	1.117	1.887	1.977	1.561	12.441	18.662	
27	5.221	5.257	4.646	1.248	0.991	0.744	1.326	1.805	1.754	1.530	9.732	16.260	
28	7.677	4.762	4.164	1.282	4.291	0.703	1.228	1.769	1.604	1.503	36.773	11.597	
29	5.568	4.561	3.766	1.370	2.069	0.667	1.132	1.680	1.500	1.506	21.609	9.743	
30	5.012	14.820	3.435	1.279	1.537	0.646	1.103		1.411	1.499	12.546	12.416	
31	4.419	8.336		1.121		0.666	1.013		1.348		10.126		
Min	3.406	4.146	3.435	1.121	0.901	0.646	0.660	0.927	1.102	1.314	1.433	3.395	0.646
Mean	5.937	9.672	8.241	2.214	1.384	1.163	1.770	2.575	1.671	2.832	8.443	7.774	4.477
Max	16.656	41.808	16.907	6.600	4.291	2.723	11.540	23.843	7.887	15.128	36.773	18.662	41.808



Flow in the Mangaehu River from July 2015 to June 2016

Source is R:\ARCHIVES\HYDRO-ARCHIVES.HTS
Flow (m^3/sec) at Mangaehu at Bridge
From 1-Jul-2015 00:00:00 to 30-Jun-2016 24:00:00
24 hour periods beginning at midnight each day.

Daily means Years 2015-2016 Flow(m^3/sec) at Mangaehu at Bridge

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
1	10.717	11.960	31.526	8.789	4.819	6.378	2.814	3.337	3.218	2.249	2.308	?	
2	9.969	16.693	35.392	24.529	4.516	6.766	3.509	2.896	2.670	11.481	2.296	?	
3	9.988	16.295	44.409	17.012	4.396	5.446	3.182	2.720	2.339	17.614	2.274	?	
4	13.330	19.993	30.358	12.130	15.269	7.077	5.045	2.556	2.206	9.501	2.305	7.255	
5	11.720	45.214	19.912	9.275	21.147	8.764	3.981	2.457	2.138	4.945	2.579	6.385	
6	9.998	87.199	16.666	7.881	8.850	5.910	2.871	2.703	2.097	3.639	4.274	5.619	
7	15.881	70.011	14.397	7.002	6.345	7.083	2.565	3.270	2.081	3.038	3.664	5.001	
8	22.445	46.139	11.470	6.814	5.371	5.802	5.080	2.714	2.109	3.063	2.731	4.680	
9	14.972	35.768	9.970	7.180	4.901	4.668	12.174	2.392	2.065	3.479	2.405	4.594	
10	24.140	23.229	10.428	6.263	4.667	4.186	7.190	2.346	1.996	3.082	2.229	6.187	
11	18.935	17.379	28.549	5.871	4.451	3.924	3.810	2.312	2.003	2.823	2.198	12.594	
12	14.293	15.049	27.006	5.512	4.247	4.371	3.157	2.186	2.056	8.110	4.926	9.103	
13	12.123	12.588	15.766	5.524	3.856	18.345	3.317	2.097	1.937	15.202	8.110	13.937	
14	10.861	11.077	12.289	7.792	3.596	13.786	3.108	2.043	1.993	7.548	6.710	10.058	
15	10.248	12.177	10.402	7.389	4.439	6.722	2.768	2.018	2.178	4.498	4.474	8.134	
16	13.090	11.914	9.424	5.513	17.952	5.516	2.586	1.977	2.115	3.592	3.164	7.253	
17	13.132	9.529	9.057	5.009	11.394	5.535	2.531	2.044	2.975	3.222	9.739	6.574	
18	16.435	8.605	36.027	5.061	6.352	5.164	2.758	11.155	8.797	3.014	14.396	6.024	
19	73.078	18.576	27.817	5.554	4.932	5.813	22.975	13.385	5.197	2.837	19.745	5.672	
20	29.633	28.896	45.747	4.879	5.330	4.331	14.588	8.503	3.208	2.654	10.314	5.406	
21	20.297	14.667	35.693	4.400	10.797	3.781	7.343	4.521	2.596	2.568	38.347	5.192	
22	15.271	11.354	22.445	4.310	13.371	3.575	4.761	3.229	2.341	2.514	27.709	8.009	
23	12.507	10.676	17.406	4.733	8.530	3.606	3.735	2.789	2.210	2.604	16.557	21.030	
24	10.951	14.410	15.436	29.424	5.950	3.485	3.201	2.608	4.014	2.876	?	29.914	
25	9.979	43.489	12.228	19.714	5.023	3.563	2.867	2.475	8.243	3.619	?	19.287	
26	9.195	57.609	10.084	8.841	4.589	3.611	2.633	2.379	4.224	3.011	?	34.714	
27	8.901	24.278	8.842	7.790	4.502	3.163	4.924	2.334	6.186	2.563	?	53.358	
28	18.475	16.081	8.012	6.719	11.830	2.875	16.491	2.428	4.250	2.433	?	44.561	
29	28.177	13.257	7.467	7.531	14.154	2.725	6.876	2.825	2.944	2.371	?	28.934	
30	19.924	16.615	6.954	7.277	7.093	2.654	4.084		2.539	2.344	?	20.580	
31	13.959	19.722		5.547		2.585	3.530		2.355		?		
Min	8.901	8.605	6.954	4.310	3.596	2.585	2.531	1.977	1.937	2.249	2.198	4.594	1.937
Mean	16.859	24.530	19.706	8.750	7.756	5.523	5.499	3.472	3.138	4.750	8.411	14.447	10.264
Max	73.078	87.199	45.747	29.424	21.147	18.345	22.975	13.385	8.797	17.614	38.347	53.358	87.199

Appendix II

TRC Lake Rotorangi water quality trend analysis 1990-2015

Memorandum

To	J Kitto, Science Advisor
From	Alex Connolly, Scientific Officer SEM
Document	#1845978
Date	31/05/2017

Lake Rotorangi trend analysis January 1990 to December 2015

Introduction

A trend analysis of Lake Rotorangi monitoring data from 1990 to 2015 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 performed 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. Table 3 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 ($p<0.05$) deterioration in nitrate nitrogen and chlorophyll at both sites individually, and very significant ($p<0.01$) deterioration when the 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 1.7% per year (or 5.5 $mgN/m^3/y$) and chlorophyll *a* is increasing by 2.2% per year (0.07 $mg/m^3/y$).

There is also significant increasing trend in dissolved oxygen at both sites individually and also combined. The PAC was calculated and indicated that, when data from sites L2 and L3 are combined, DO is increasing by 0.6% per year (or 0.03 $mg/m^3/y$).

There is also a significant increasing trend at the L2 site and L2 and L3 sites combined for temperature. The PAC was calculated and indicated that, when data from sites L2 and L3 are combined, temperature is increasing by 0.2% per year (or 0.03°C/y).

The trend for total suspended solids in previous years has shown significant improvement (i.e. a decline of 4.2% per year (0.16 mg/m3/y) Hafiz, 2014 trend report). However in this year's 2015 trend analysis no significant trends were detected for suspended solids at either of the sites. It is thought that this may be due to the sharp spike in TSS recorded in the June 2015 survey (Figure 3), this spike in TSS has been attributed to a flood event leading to the Patea Dam releasing flows higher than ever before. The lake at this time was completely mixed; there was no stratification and this may have also led to a temperature increase, noted at this June survey. This large increase in TSS has probably affected the trends over the entire trend period hence why the improving trends have ceased for suspended solids in this 2015 trend analysis. Figure 1 and Figure 2 present the significant trends graphically for the combined sites data. Figure 3 presents the TSS trend data, although there was no significant trend detected in this year's analysis. Trends are presented graphically for all parameters for combined sites (Appendix 2) and individual sites (Appendices 3 and 4).

Table 1 Trends in water quality parameters in Lake Rotorangi for monitoring conducted from 1990 to 2015

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

Key:

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

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

😐 **no statistically significant change**

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

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

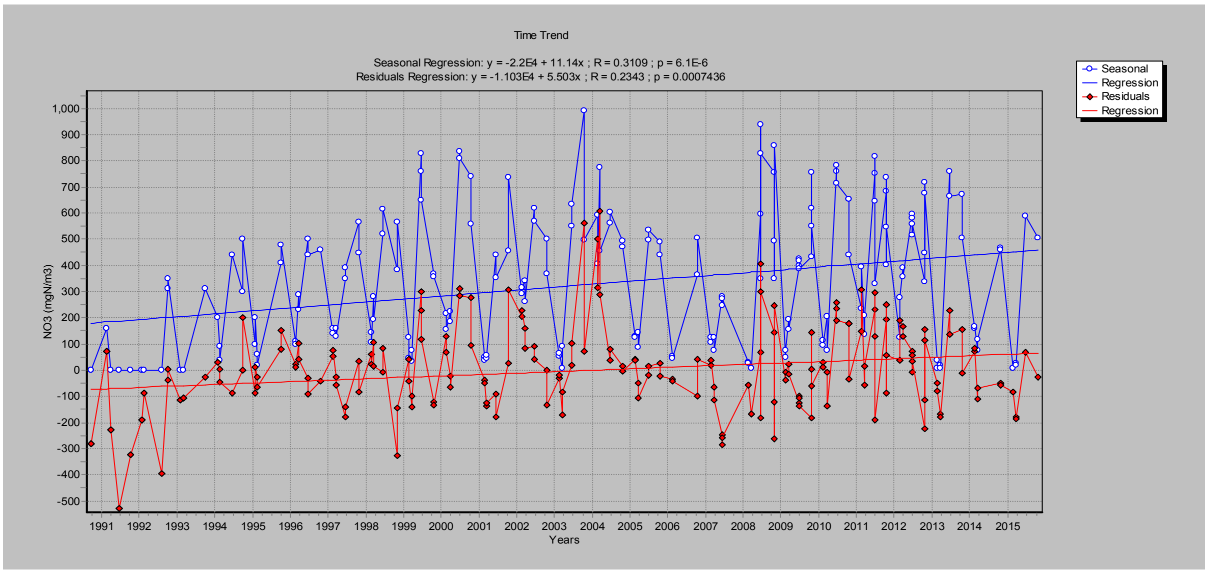


Figure 1: Nitrate nitrogen (NO3) trend line for sites L2 and L3 combined

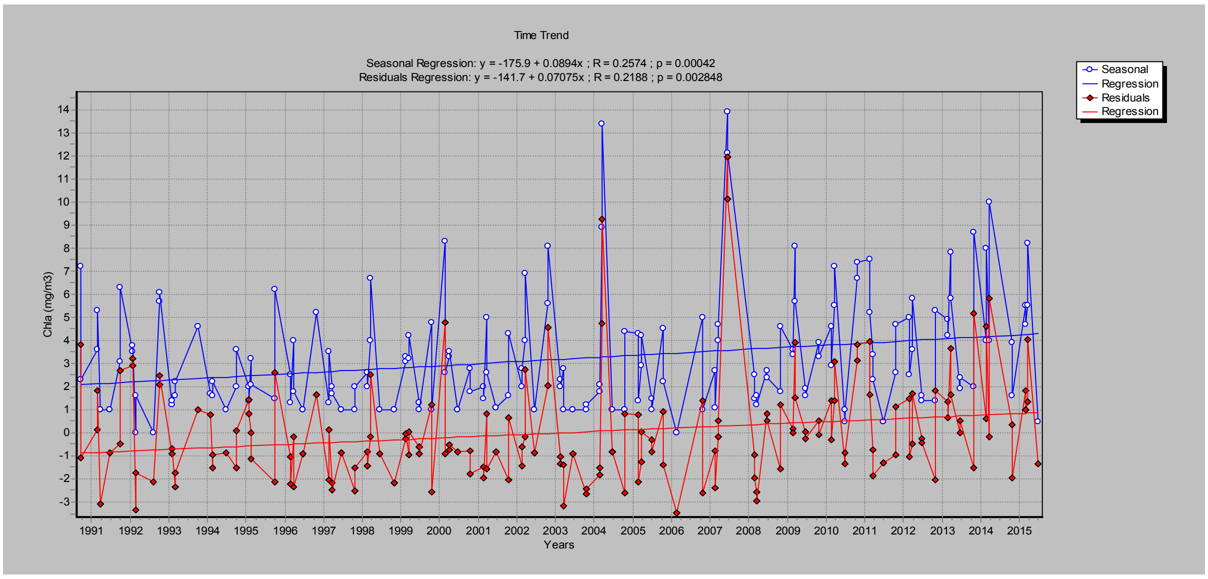


Figure 2: Chlorophyll a trend line for sites L2 and L3 combined

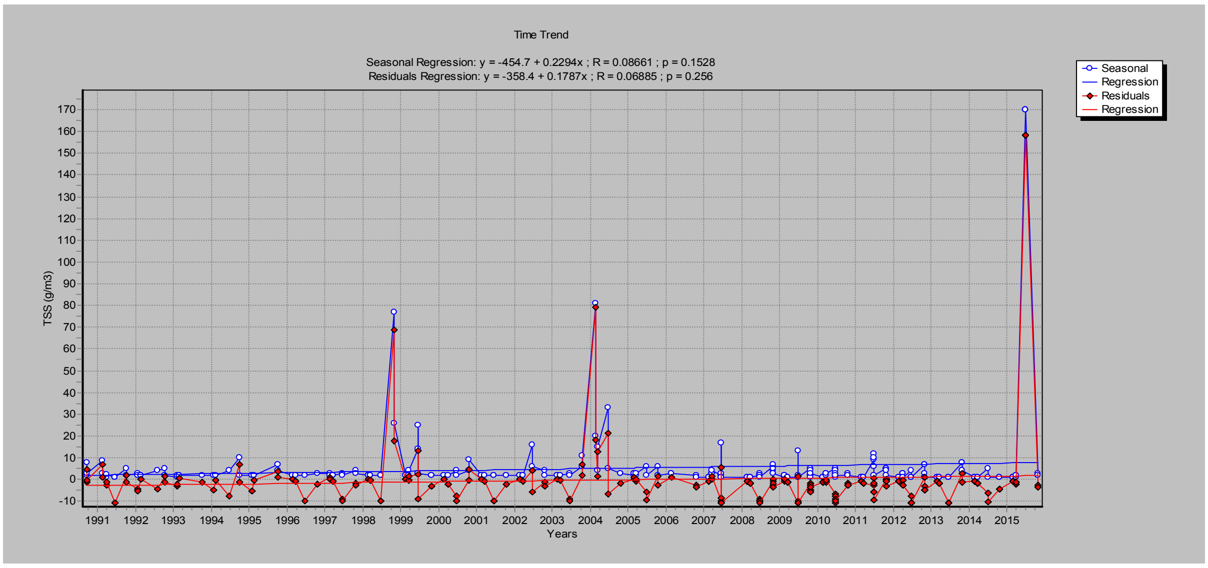


Figure 3: Total suspended solids trend line for sites L2 and L3 combined

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

The average TLI for the 1990-2015 period is 4.16 (±0.06) (Table 2 in Appendix 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* indicates that the lake is in a mesotrophic state, and the secchi depth and nutrients indicate a eutrophic state (see highlighted areas in Table 2).

When the sites are looked at individually the TLI of L2 continues to be slightly eutrophic however L3 is within the mesotrophic boundary. Therefore site L2 continues to be more eutrophic at a TLI of 4.24 (possibly as a result of this site's proximity to the upper catchment) due to the higher total nitrogen level and lower secchi depth (refer to Appendices 2 and 3). The L2 TLI for chlorophyll *a* and secchi depth indicated a mesotrophic state and the nutrients (total phosphorus and total nitrogen) indicate a eutrophic state. The L3 TLI (3.88) indicated mesotrophic conditions in the 2015 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 a significant trend for NO_3, suggests that the trophic level is increasing, albeit at a very small rate of change (0.01 ±0.01 units per year), which he notes is not a cause for major concern. The current trend analysis continues to support this conclusion.

Table 2 Values of key variables that define the boundaries of different Trophic Levels (highlighted areas relate to the status of Lake Rotorangi using 1990-2015 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

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 the Job Manager from past assessments of the stratification depth profiles. The HVOD *p* values indicate that there has been no significant change over the 1990-2015 period. Furthermore the HVOD parameter has been the subject of discussion at a national level and it has not been recommended for annual use in future national monitoring and reporting (NIWA, 2011). While TRC currently provides a yearly HVOD summary, on the basis of work currently being undertaken by NIWA and MfE, it may not be applicable for future HVOD analysis of Lake Rotorangi data. There have also been discrepancies over HVOD data currently stored in Lakewatch due to some difficulties with using the software in the 2014 analysis; interpretation of these 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 3 *p* and R values for trend analysis of 1990-2015 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*	0.03	0.23	0.04	0.21	0.003	0.22
DO	0.04	0.21	0.006	0.27	0.002	0.22
EC	0.03	0.18	0.53	0.06	0.06	0.12
Secchi Depth	0.58	0.06	0.31	-0.10	0.67	-0.03
TSS	0.95	-0.005	0.12	0.13	0.26	0.07
Temperature	0.10	0.16	0.04	0.20	0.01	0.18
DRP	0.29	0.11	0.99	0.002	0.34	0.06
NH_4	0.85	-0.019	0.67	0.04	0.95	0.005
NO_3	0.02	0.22	0.01	0.25	0.0007	0.23
TN	0.84	-0.02	0.94	-0.006	0.85	-0.01
TP	0.96	-0.005	0.11	0.16	0.21	0.09
HVOD	0.50	0.14	0.09	-0.35	0.26	-0.30
TLI	0.57	0.06	0.04	0.23	0.21	0.12

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.

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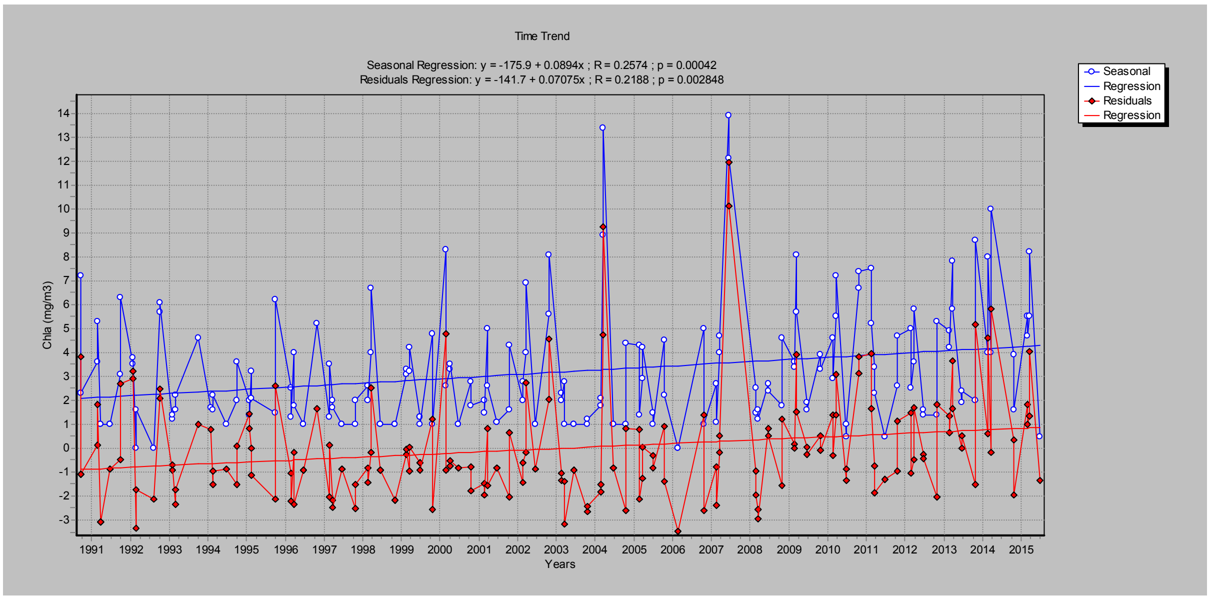
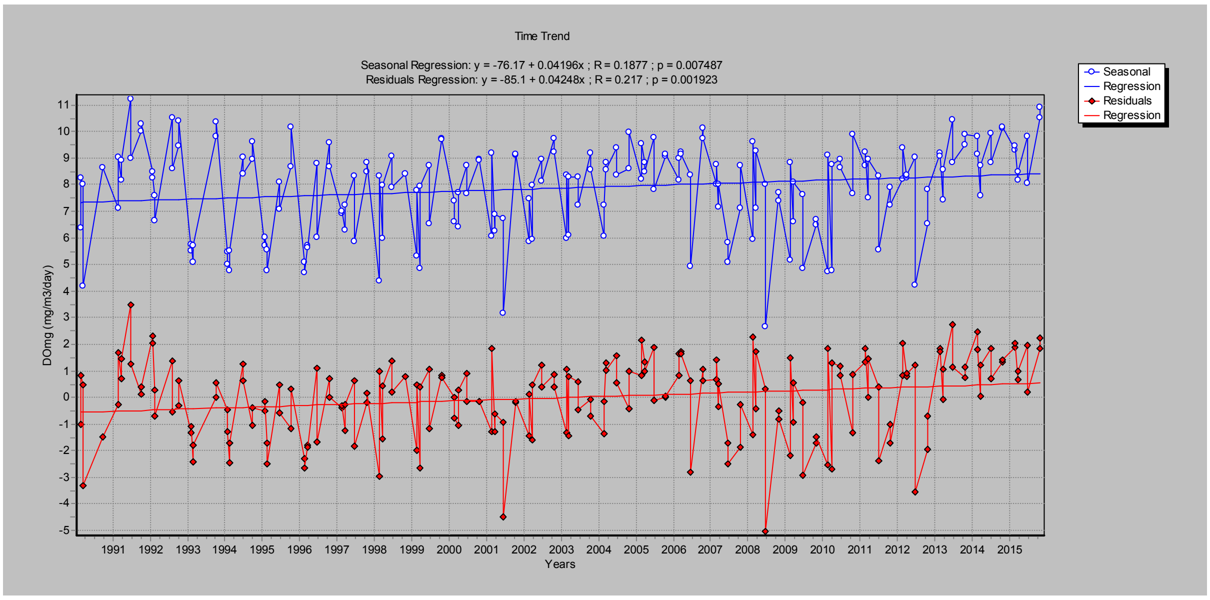
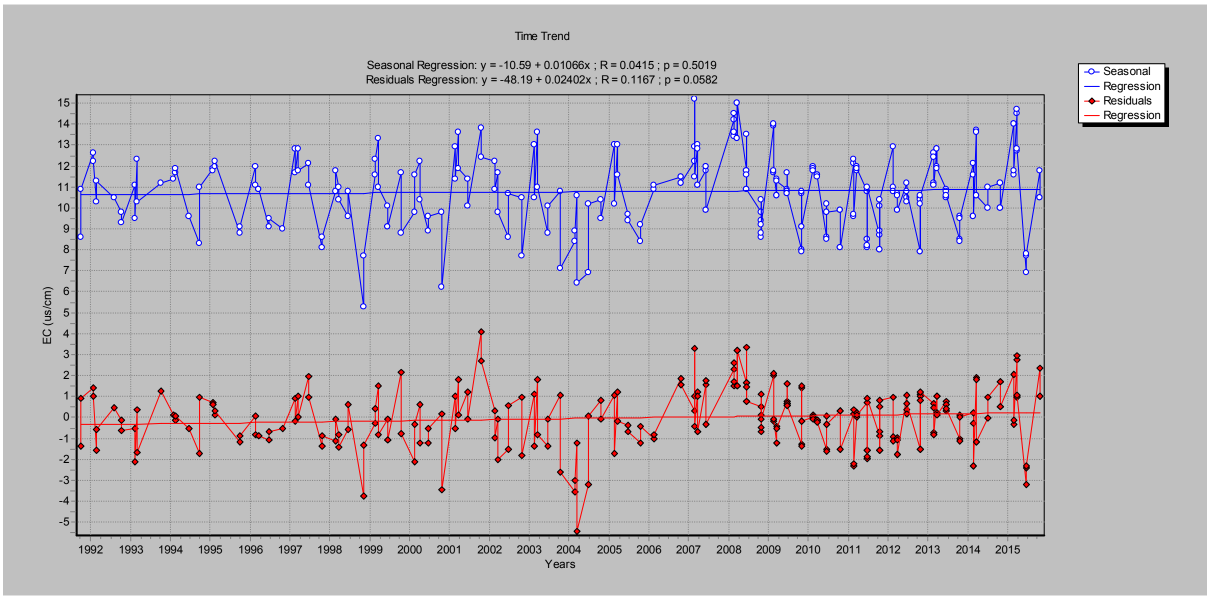
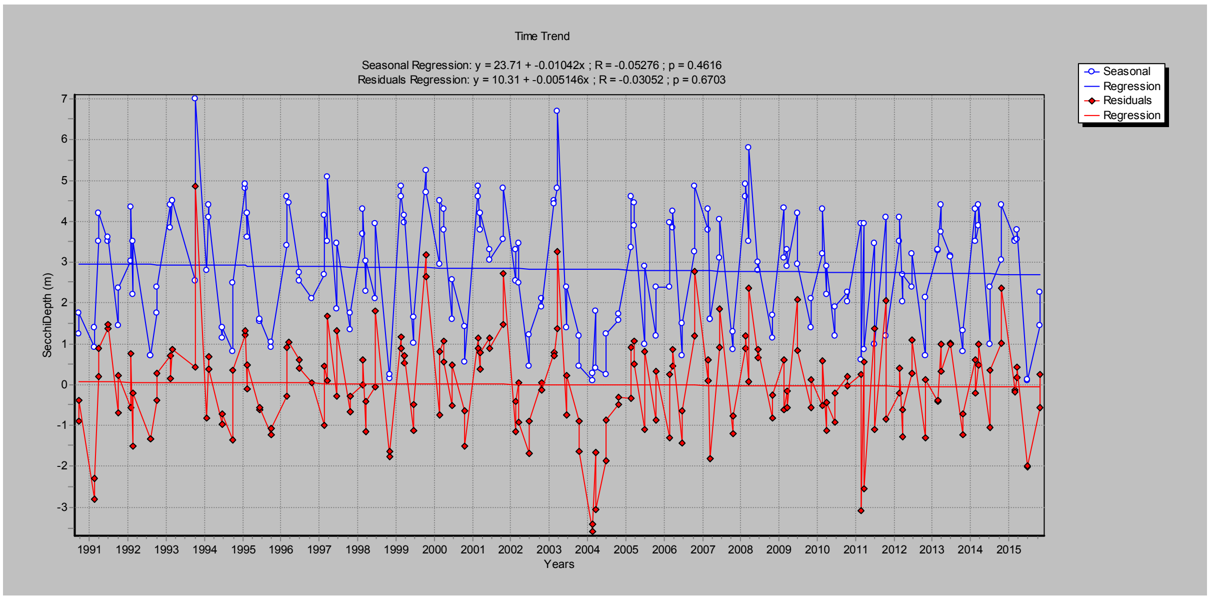
<u>Appendix 2</u>

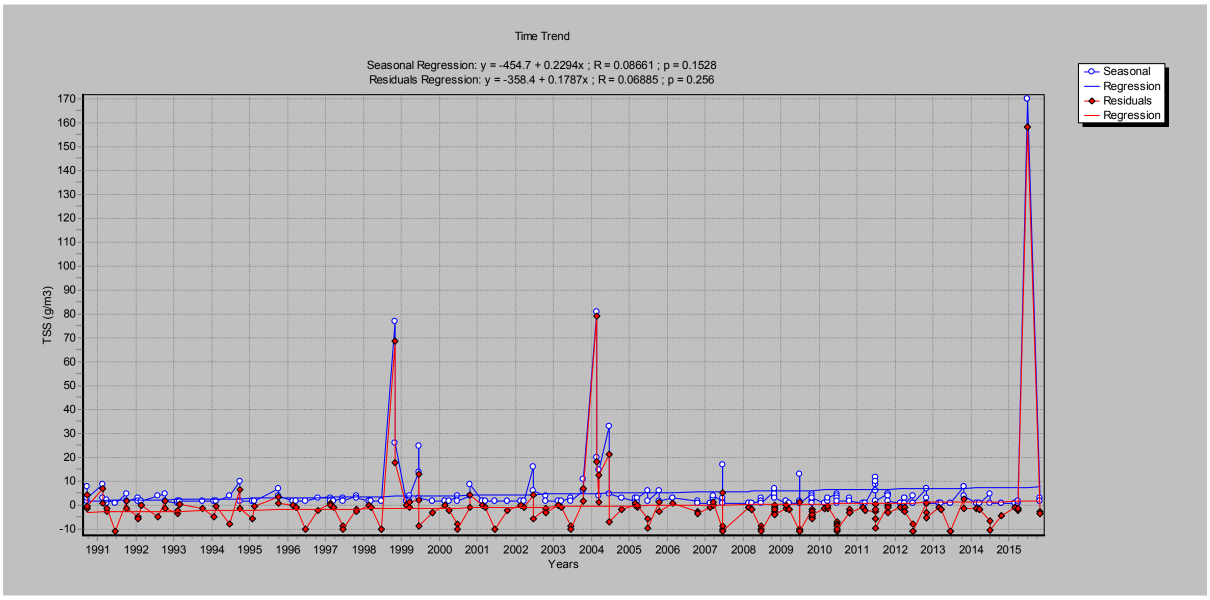
L2 and L3 combined – Physical parameters

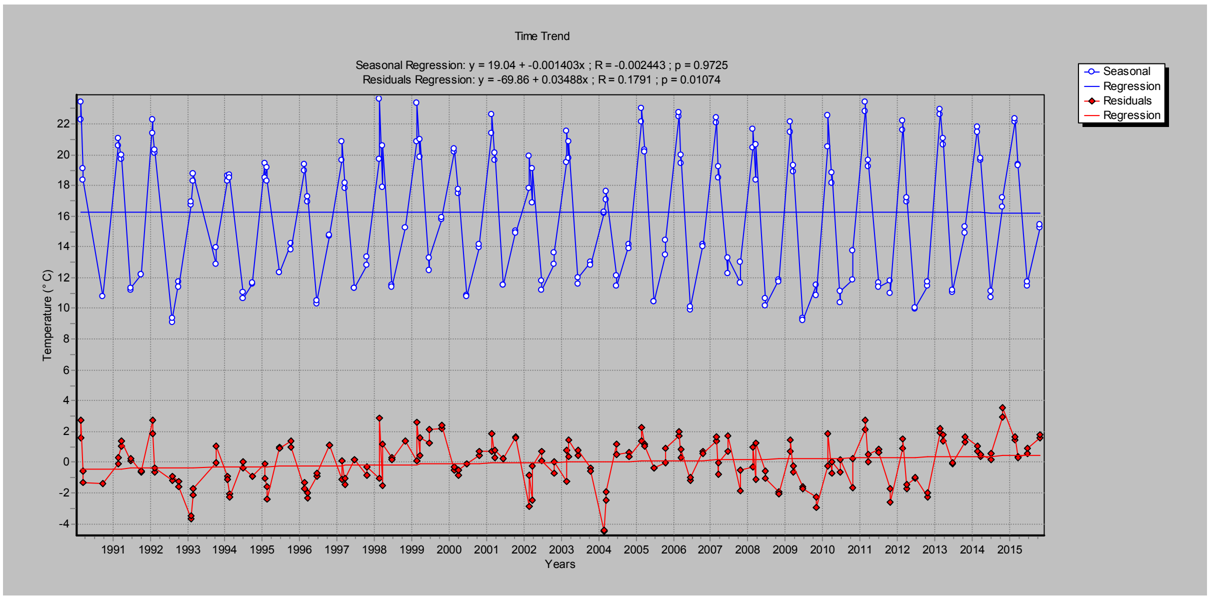




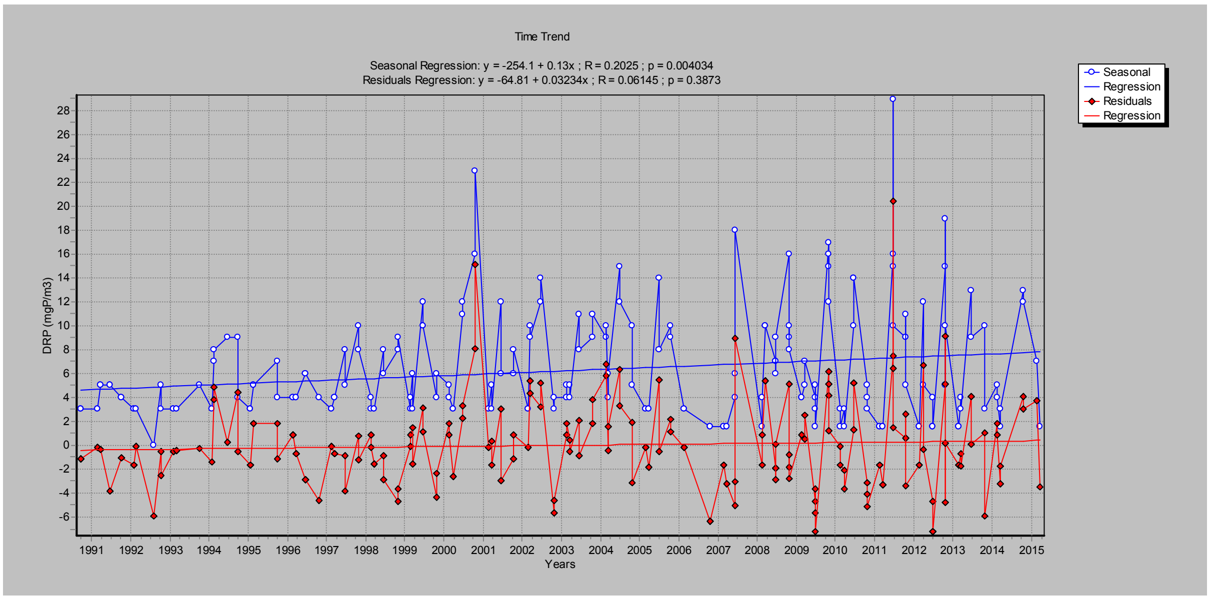

Time Trend
Seasonal Regression: y = -10.59 + 0.01066x ; R = 0.0415 ; p = 0.5019
Residuals Regression: y = -48.19 + 0.02402x ; R = 0.1167 ; p = 0.0582
Seasonal
Regression
Residuals
Regression
EC (us/cm)
Years

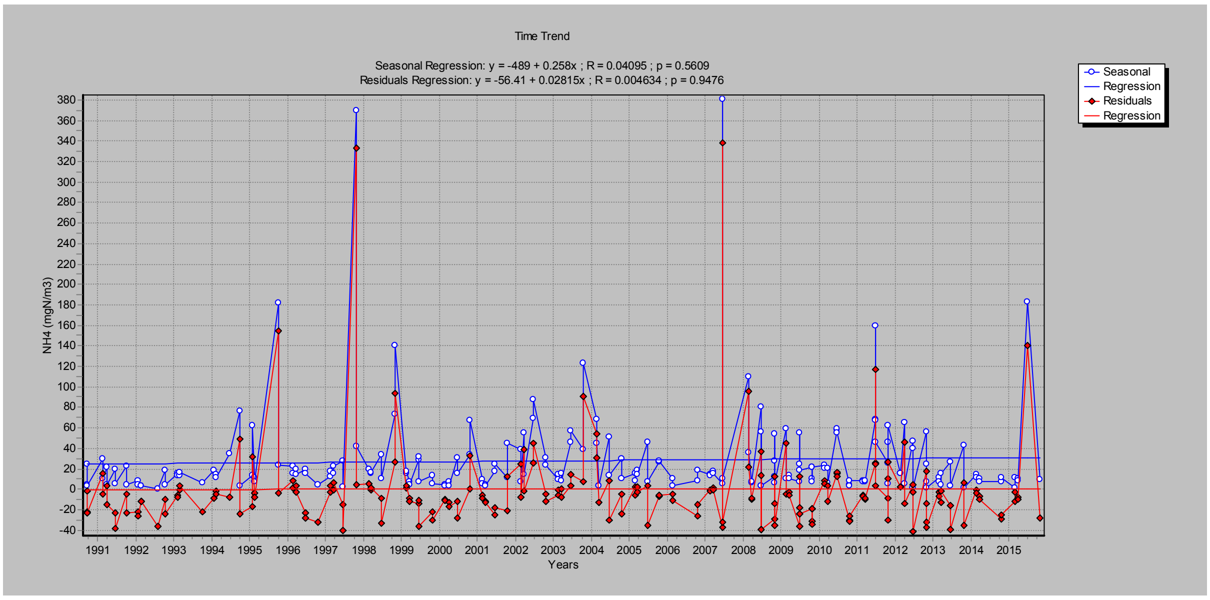

Time Trend
Seasonal Regression: y = 23.71 + -0.01042x ; R = -0.05276 ; p = 0.4616
Residuals Regression: y = 10.31 + -0.005146x ; R = -0.03052 ; p = 0.6703
Seasonal
Regression
Residuals
Regression
SecchiDepth (m)
Years

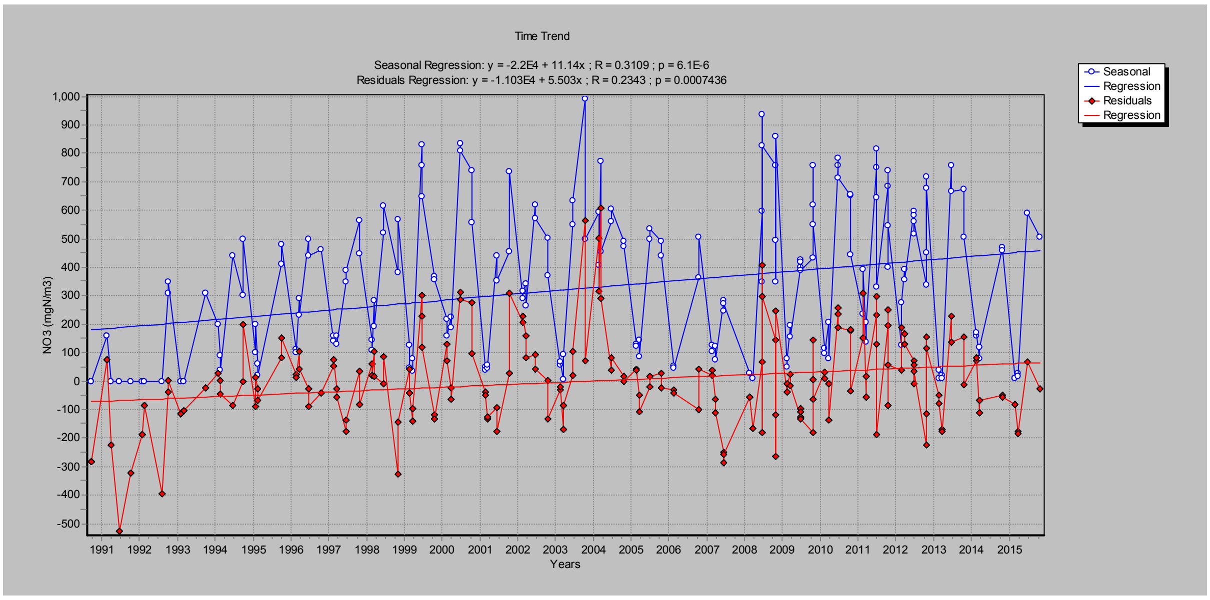

Time Trend
Seasonal Regression: y = -454.7 + 0.2294x ; R = 0.08661 ; p = 0.1528
Residuals Regression: y = -358.4 + 0.1787x ; R = 0.06885 ; p = 0.256
Seasonal
Regression
Residuals
Regression
TSS (g/m3)
Years


Time Trend
Seasonal Regression: y = 19.04 + -0.001403x ; R = -0.002443 ; p = 0.9725
Residuals Regression: y = -69.86 + 0.03488x ; R = 0.1791 ; p = 0.01074
Seasonal
Regression
Residuals
Regression
Temperature (° C)
Years
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015
22 20 18 16 14 12 10 8 6 4 2 0 -2 -4

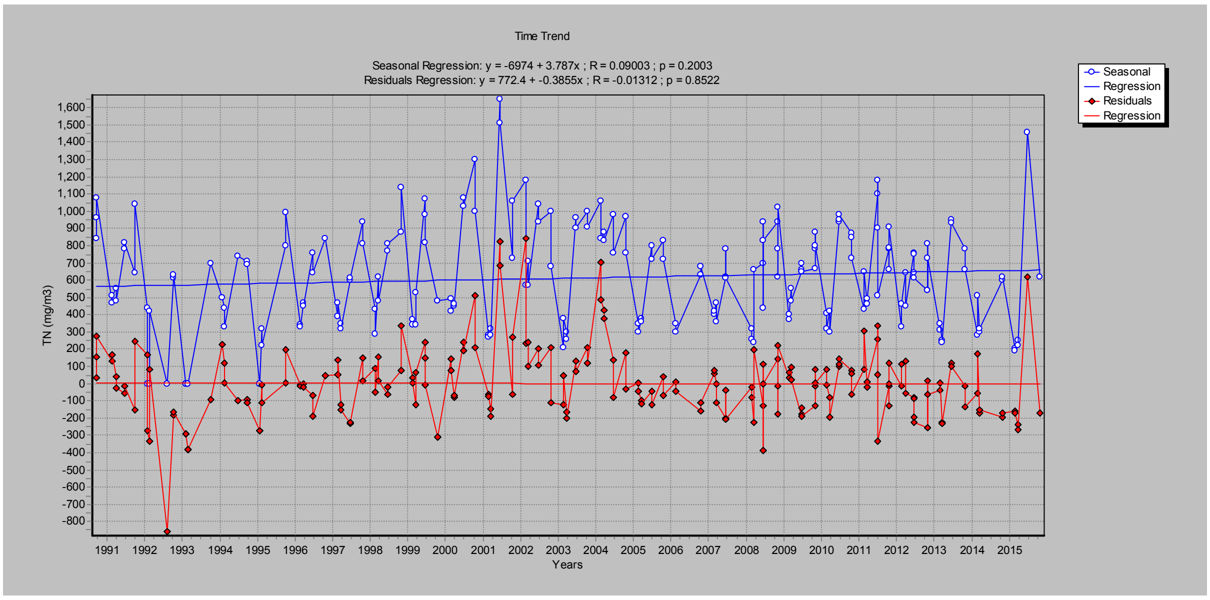
<u>Nutrients- L2 and L3 combined</u>



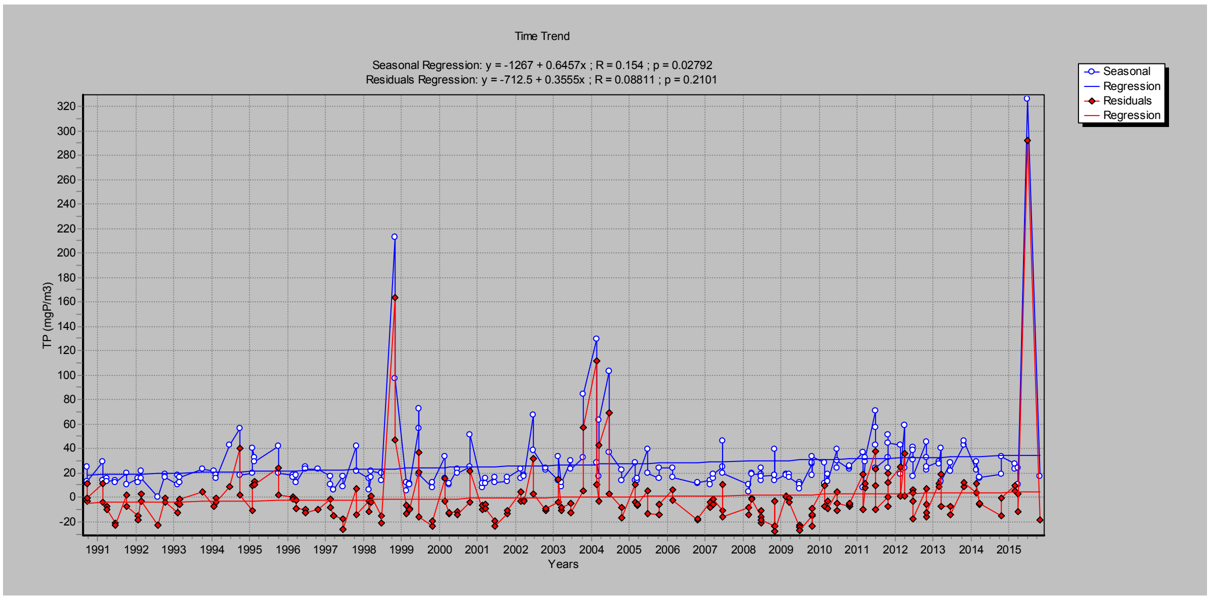




Time Trend
Seasonal Regression: y = -2.2E4 + 11.14x ; R = 0.3109 ; p = 6.1E-6
Residuals Regression: y = -1.103E4 + 5.503x ; R = 0.2343 ; p = 0.0007436
Seasonal
Regression
Residuals
Regression
NO3 (mgN/m3)
Years



Time Trend
Seasonal Regression: y = -6974 + 3.787x ; R = 0.09003 ; p = 0.2003
Residuals Regression: y = 772.4 + -0.3855x ; R = -0.01312 ; p = 0.8522
Seasonal
Regression
Residuals
Regression
TN (mg/m3)
Years



Time Trend
Seasonal Regression: y = -1267 + 0.6457x ; R = 0.154 ; p = 0.02792
Residuals Regression: y = -712.5 + 0.3555x ; R = 0.08811 ; p = 0.2101
Seasonal
Regression
Residuals
Regression
TP (mgP/m3)
Years

HVOD Analysis

Lake: LAKE ROTORANGI

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

Date From: 01/01/1990 **Date To:** 31/12/2015

Analysis Period	Average	Observed DO	Observed Rate Corrected to 10.0 °C (mg/m3/day)
01-Jan-1990 - 31-Mar-1990	10.51	1.1	1.0
01-Jan-1991 - 31-Mar-1991	11.59	12.3	11.0
01-Jan-1992 - 30-Mar-1992	9.85	10.1	10.2
01-Jan-1993 - 31-Mar-1993	9.4	-1.2	-1.3
01-Jan-1994 - 31-Mar-1994	8.55	18.8	20.8
01-Jan-1995 - 31-Mar-1995	11.1	40.2	37.3
01-Jan-1996 - 30-Mar-1996	8.94	27.3	29.4
01-Jan-1997 - 31-Mar-1997	8.66	14.5	16.0
01-Jan-1998 - 31-Mar-1998	8.31	5.6	6.3
01-Jan-1999 - 31-Mar-1999	13.32	13.7	10.9
01-Jan-2000 - 04-Apr-2000	10.12	5.6	5.6
01-Jan-2001 - 31-Mar-2001	11.08	16.4	15.2
01-Jan-2002 - 31-Mar-2002	8.73	8.9	9.8
01-Jan-2003 - 31-Mar-2003	9.66	-0.4	-0.4
01-Jan-2005 - 31-Mar-2005	8.94	37.0	39.8
01-Jan-2006 - 31-Mar-2006	9.42	19.1	19.9
01-Jan-2007 - 31-Mar-2007	12.39	5.7	4.8
01-Jan-2008 - 30-Mar-2008	9.49	4.8	5.0
01-Jan-2009 - 31-Mar-2009	10.06	10.2	10.2
01-Jan-2010 - 31-Mar-2010	8.97	-18.0	-19.3
01-Jan-2011 - 31-Mar-2011	10.25	24.0	23.6
01-Jan-2012 - 30-Mar-2012	9.84	-5.9	-6.0
01-Jan-2013 - 31-Mar-2013	9.93	13.0	13.1
01-Jan-2014 - 31-Mar-2014	11.03	-3.5	-3.3
01-Jan-2015 - 31-Mar-2015	9.63	2.2	2.2
Average	**9.99**	**10.5**	**10.5**

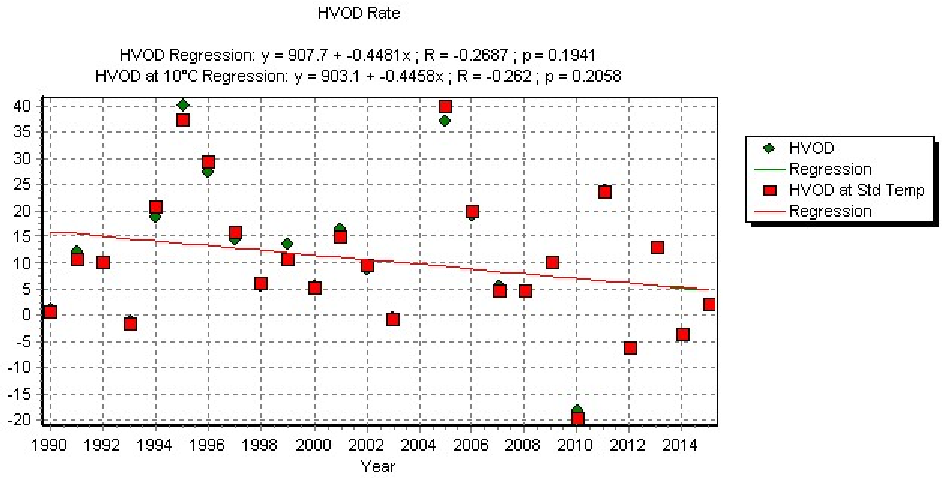
HVOD Analysis

Lake: LAKE ROTORANGI

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

Date From: 01/01/1990 **Date To:** 31/12/2015

Analysis Period	Average	Observed DO	Observed Rate Corrected to 10.0 °C (mg/m3/day)



LAKE ROTORANGI

L2 & L3 1990-2015 (1 Jan 1990 - 31 Dec 2015)

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)	(0.01)	(-0.88)	(-0.45)			
Average Over Period	3.15	(2.82)	(25.06)	(607.19)	(10.47)			
Percent Annual Change (%/Year)	**2.22**	**0.00**	**0.00**	**0.00**	**0.00**	**0.44**	**0.44**	**0.37**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Jan 1990 - Dec 1990	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			
Jan 2013 - Dec 2013	5.68	2.89	27.25	287.50	4.14	4.28	4.41	3.79	4.15	0.13			
Jan 2014 - Dec 2014	5.98	3.37	20.20	402.00	4.19	4.09	4.03	4.23	4.14	0.05			
Jan 2015 - Dec 2015	5.97	2.29	20.20	296.00	4.19	4.56	4.03	3.83	4.15	0.15			
Averages	**3.27**	**2.80**	**24.51**	**589.90**	**3.44**	**4.36**	**4.19**	**4.64**	**4.16**	**0.06**	**0.01**	**0.01**	**0.2134**

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 = 0.44 ± 0.44 % per year
P-Value = 0.37

TLI Value = 4.16 ± 0.06 TLI units
TLI Trend = 0.01 ± 0.01 TLI units per year
P-Value = 0.2134

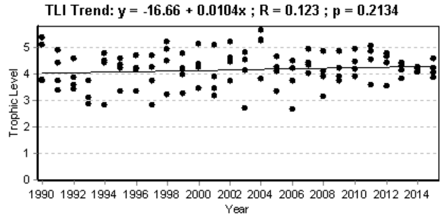
ASSESSMENT:

Eutrophic
No Change

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

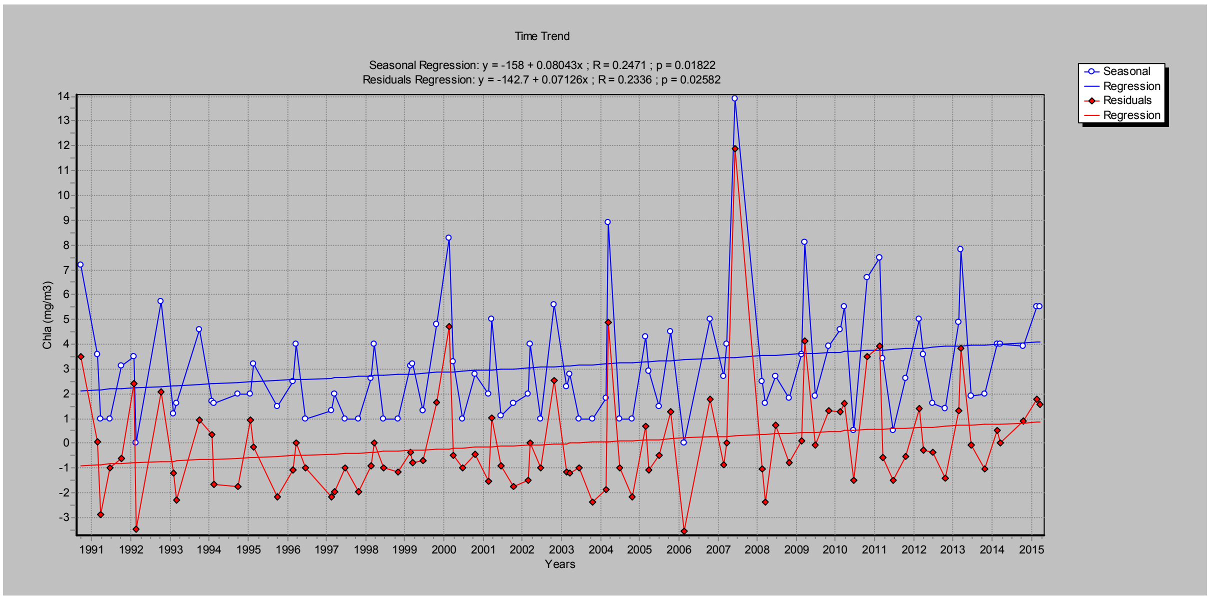
P-Value Range	Interpretation
P ≤ 0.1	Definite Change
0.1 < P ≤ 0.2	Probable Change
0.2 < P ≤ 0.3	Possible Change
0.3 < P	No Change

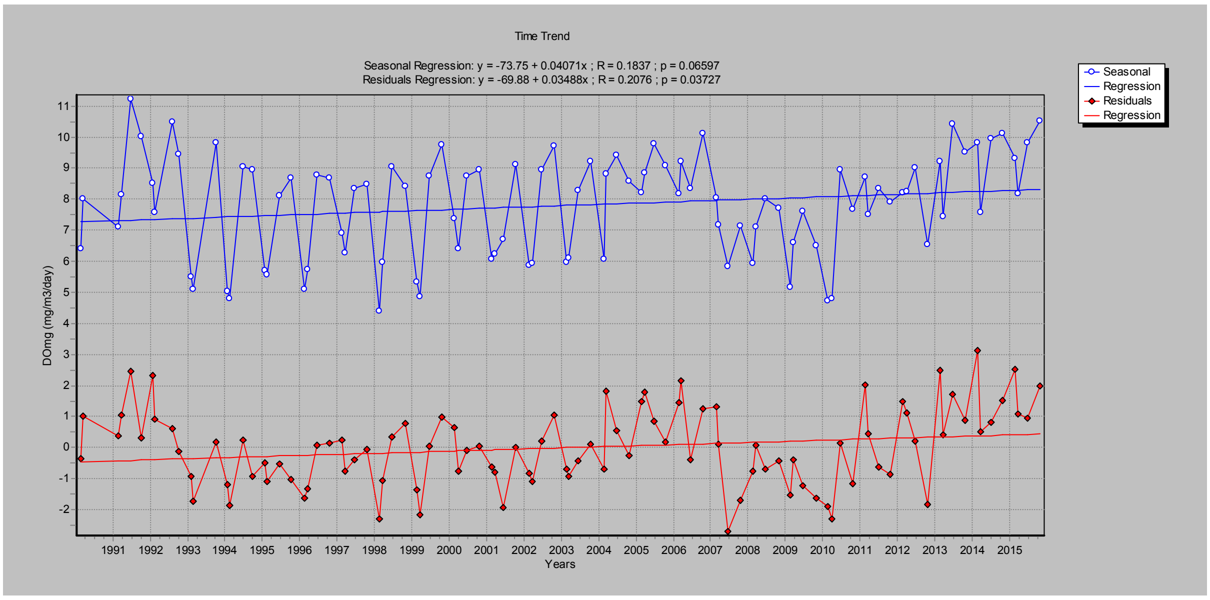
TLI Trend: y = -16.66 + 0.0104x ; R = 0.123 ; p = 0.2134

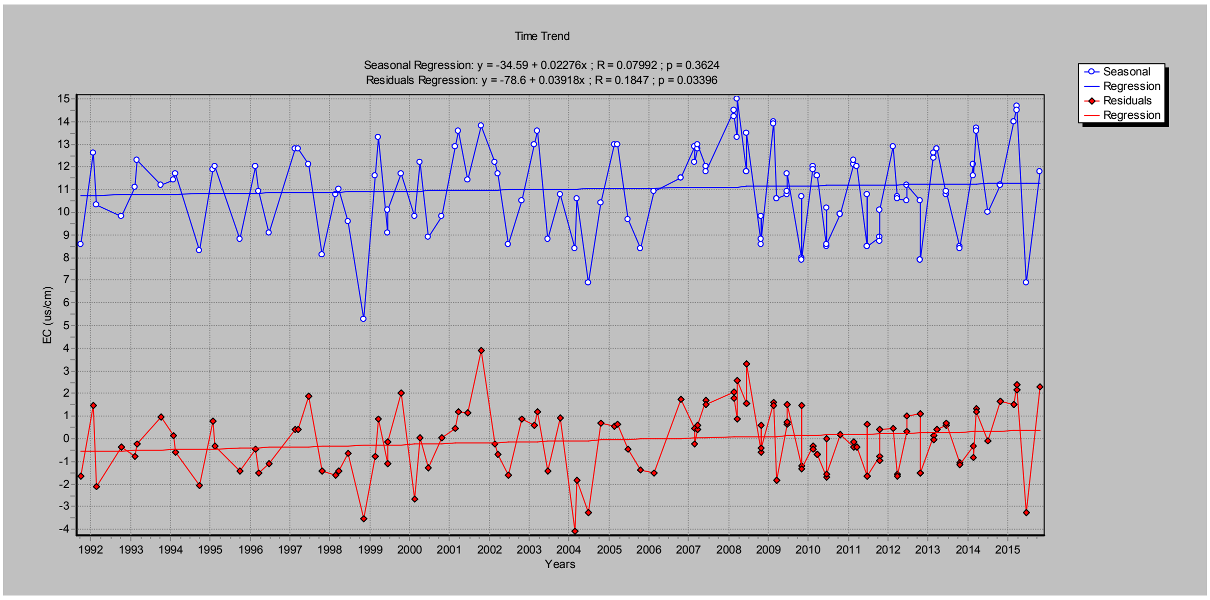


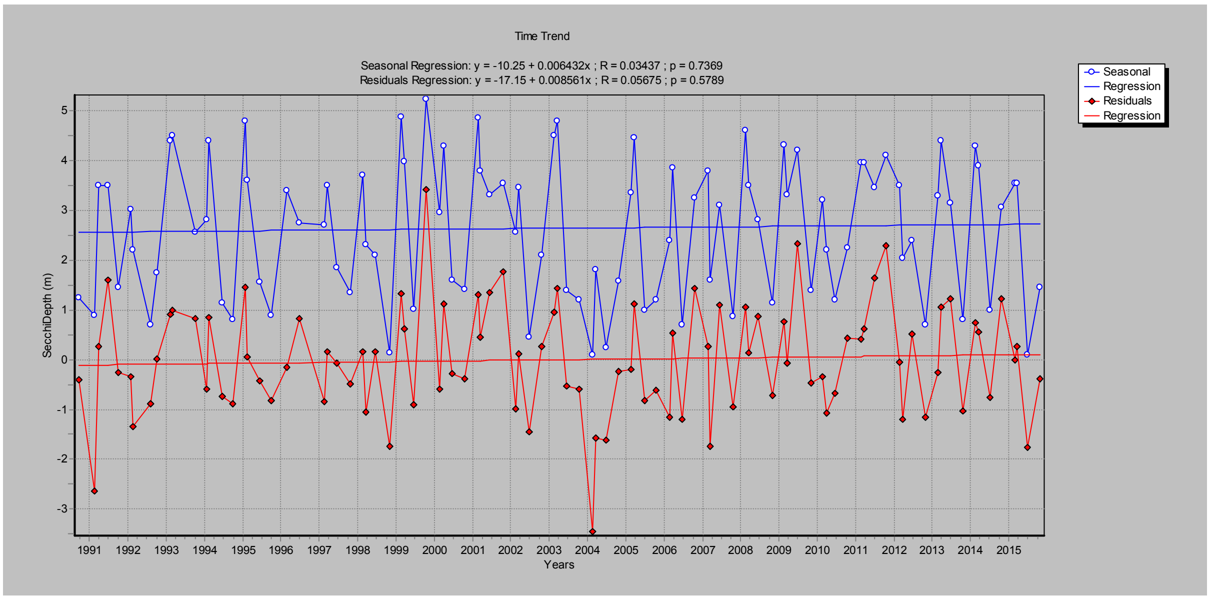
Appendix 3

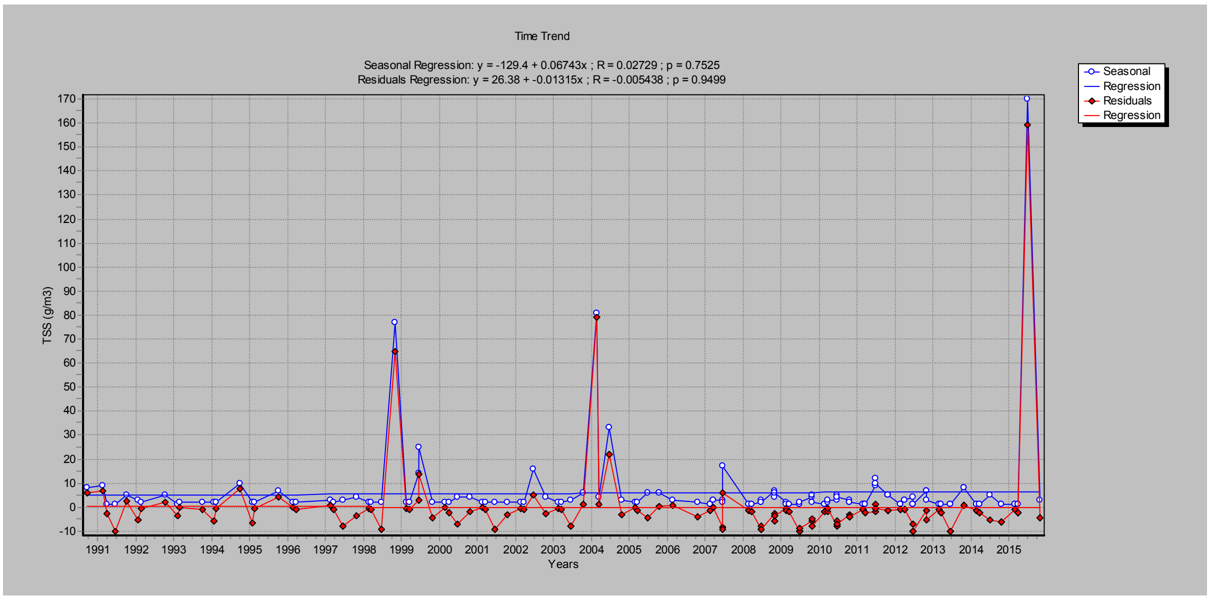
L2 trends – Physical parameters



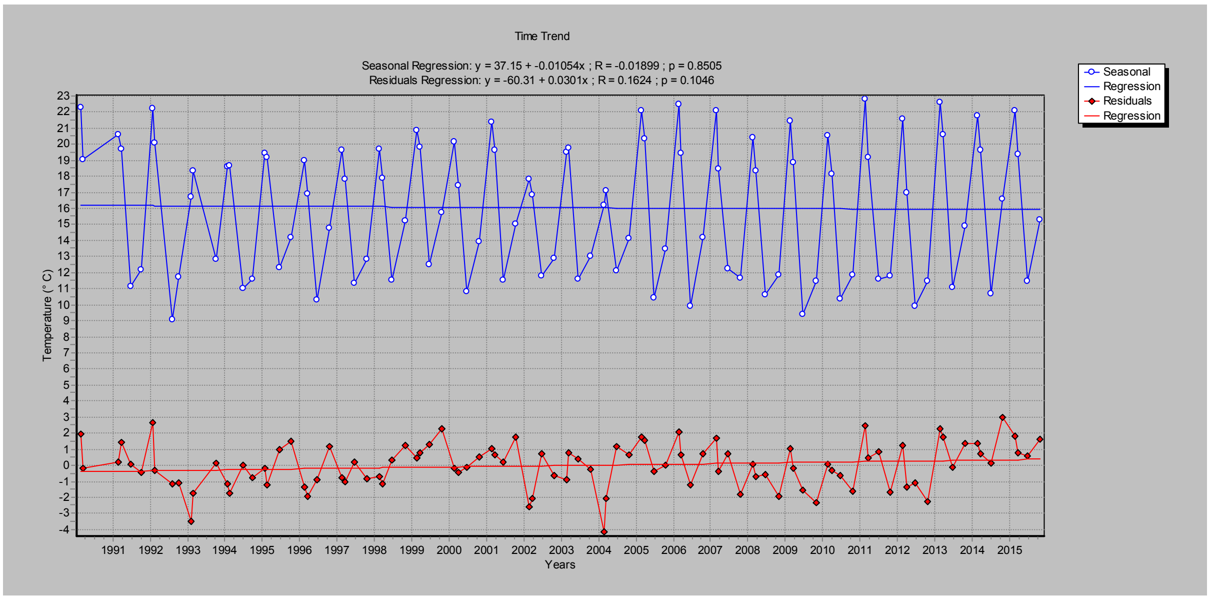



Time Trend
Seasonal Regression: y = -34.59 + 0.02276x ; R = 0.07992 ; p = 0.3624
Residuals Regression: y = -78.6 + 0.03918x ; R = 0.1847 ; p = 0.03396
Seasonal
Regression
Residuals
Regression
EC (us/cm)
Years
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015


Time Trend
Seasonal Regression: y = -10.25 + 0.006432x ; R = 0.03437 ; p = 0.7369
Residuals Regression: y = -17.15 + 0.008561x ; R = 0.05675 ; p = 0.5789
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
2013
2014
2015

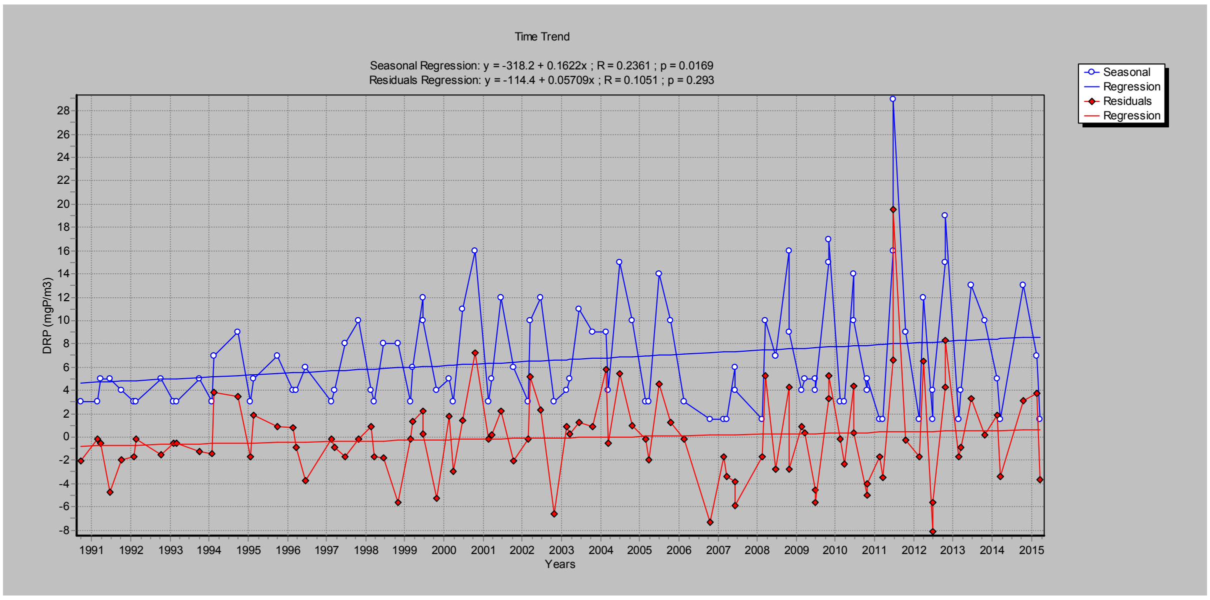


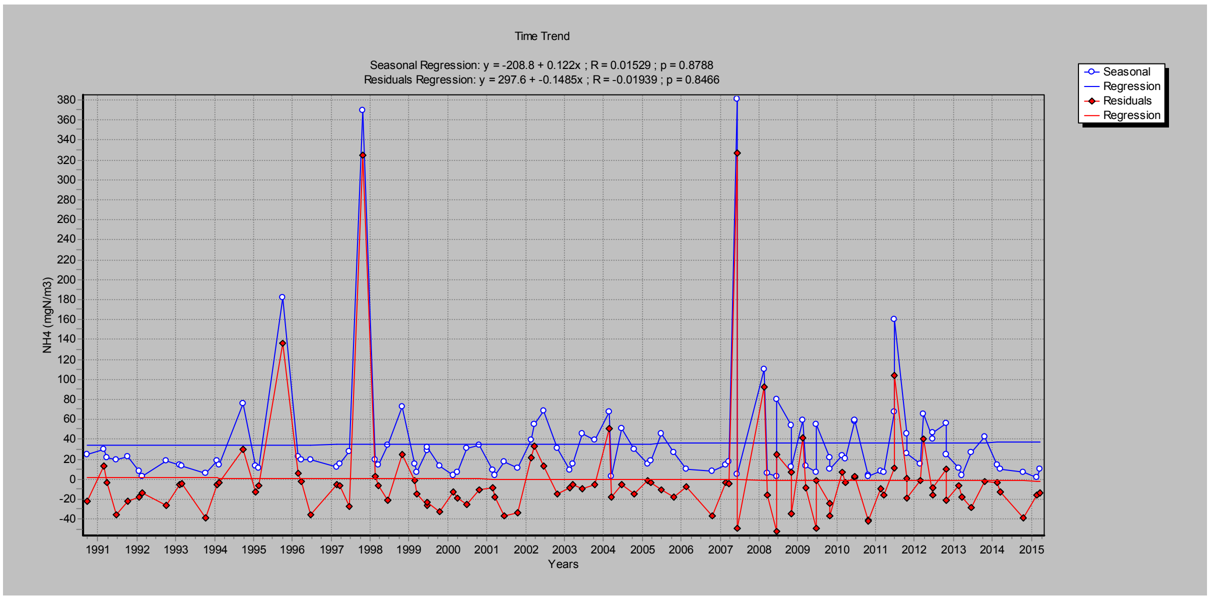
Time Trend
Seasonal Regression: y = -129.4 + 0.06743x ; R = 0.02729 ; p = 0.7525
Residuals Regression: y = 26.38 + -0.01315x ; R = -0.005438 ; p = 0.9499
TSS (g/m3)
Years
Seasonal
Regression
Residuals
Regression

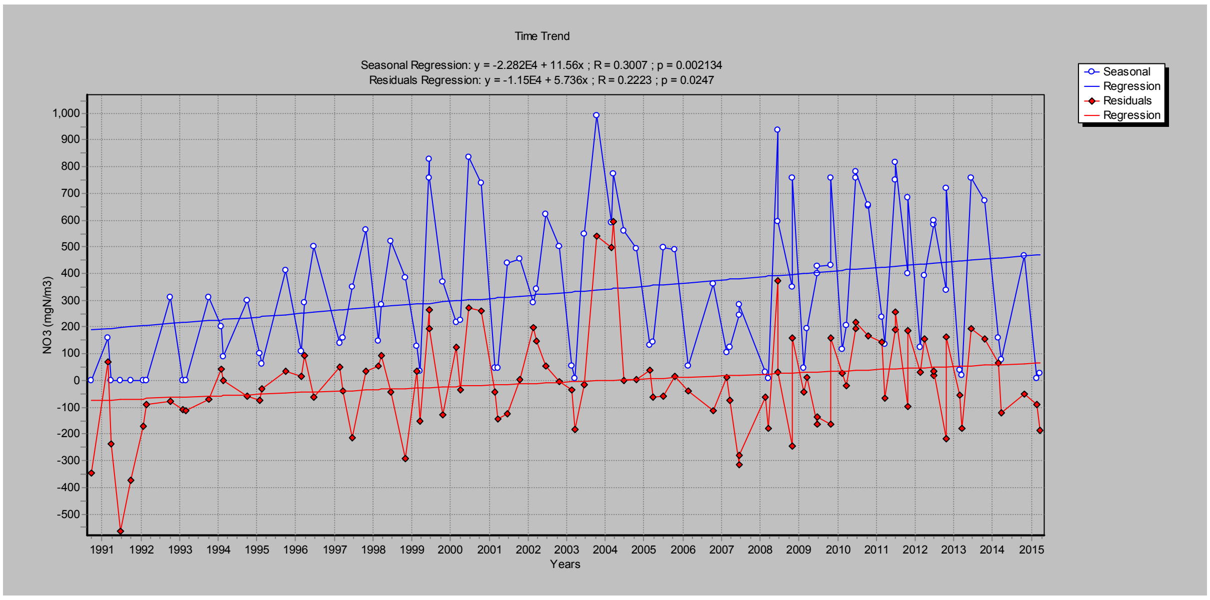


Time Trend
Seasonal Regression: y = 37.15 + -0.01054x ; R = -0.01899 ; p = 0.8505
Residuals Regression: y = -60.31 + 0.0301x ; R = 0.1624 ; p = 0.1046
Temperature (° C)
Years
Seasonal
Regression
Residuals
Regression

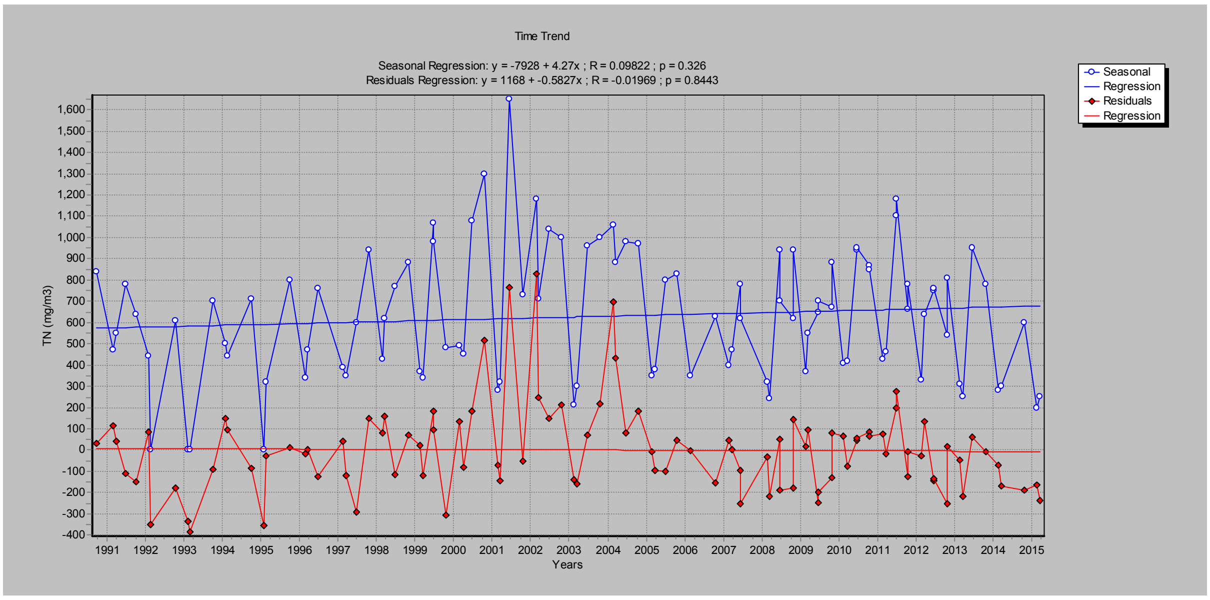
L2 - Nutrients



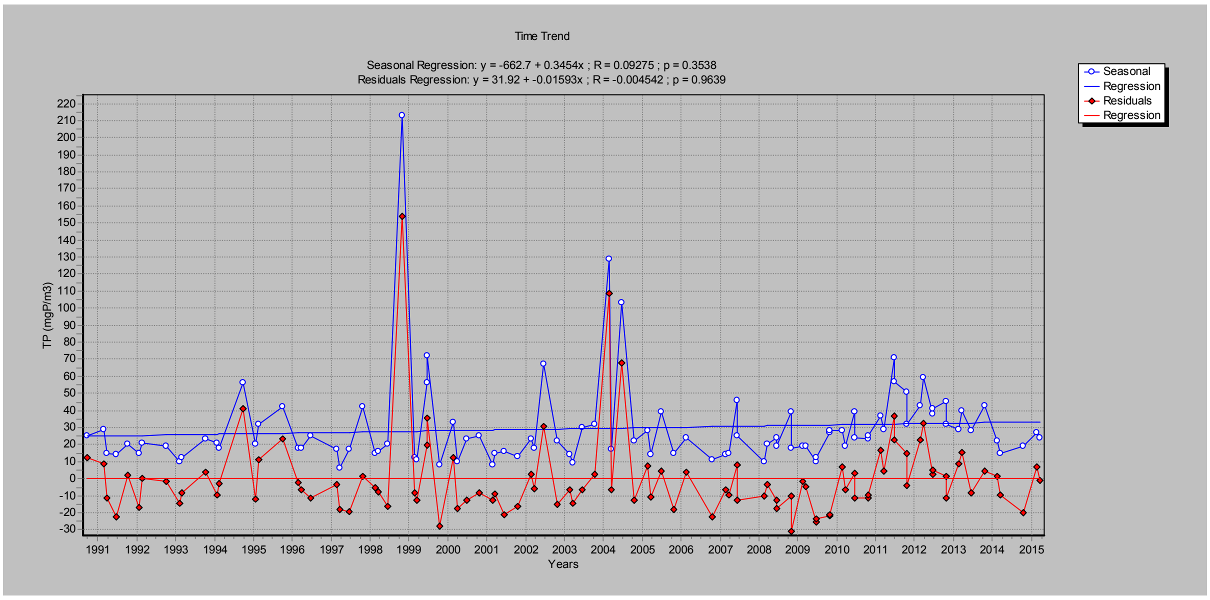




Time Trend
Seasonal Regression: y = -2.282E4 + 11.56x ; R = 0.3007 ; p = 0.002134
Residuals Regression: y = -1.15E4 + 5.736x ; R = 0.2223 ; p = 0.0247
Seasonal
Regression
Residuals
Regression
NO3 (mgN/m3)
Years



Time Trend
Seasonal Regression: y = -7928 + 4.27x ; R = 0.09822 ; p = 0.326
Residuals Regression: y = 1168 + -0.5827x ; R = -0.01969 ; p = 0.8443
Seasonal
Regression
Residuals
Regression
TN (mg/m3)
Years



Time Trend
Seasonal Regression: y = -662.7 + 0.3454x ; R = 0.09275 ; p = 0.3538
Residuals Regression: y = 31.92 + -0.01593x ; R = -0.004542 ; p = 0.9639
Seasonal
Regression
Residuals
Regression
TP (mgP/m3)
Years

HVOD Analysis

Lake: LAKE ROTORANGI

Stations: L2 (Tangahoe Valley Rd)

Date From: 01/01/1990 **Date To:** 31/12/2015

Analysis Period	Average	Observed DO	Observed Rate Corrected to 10.2 °C (mg/m3/day)
01-Jan-1990 - 31-Mar-1990	11.7	-43.3	-39.0
01-Jan-1991 - 31-Mar-1991	11.58	5.1	4.7
01-Jan-1992 - 30-Mar-1992	9.94	5.6	5.7
01-Jan-1993 - 31-Mar-1993	9.4	-11.2	-11.8
01-Jan-1994 - 31-Mar-1994	8.72	-35.2	-39.0
01-Jan-1995 - 31-Mar-1995	11.58	30.7	27.9
01-Jan-1996 - 30-Mar-1996	9.29	8.9	9.5
01-Jan-1997 - 31-Mar-1997	8.82	-24.8	-27.3
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-2003 - 31-Mar-2003	10.3	-39.2	-39.0
01-Jan-2005 - 31-Mar-2005	9.03	19.0	20.7
01-Jan-2006 - 31-Mar-2006	9.51	19.4	20.4
01-Jan-2007 - 31-Mar-2007	12.71	14.5	12.2
01-Jan-2008 - 30-Mar-2008	9.73	-6.5	-6.7
01-Jan-2009 - 31-Mar-2009	10.36	-9.4	-9.3
01-Jan-2010 - 31-Mar-2010	8.96	-20.4	-22.3
01-Jan-2011 - 31-Mar-2011	10.63	9.5	9.2
01-Jan-2012 - 30-Mar-2012	10.11	-18.1	-18.2
01-Jan-2013 - 31-Mar-2013	10.07	6.4	6.5
01-Jan-2014 - 31-Mar-2014	11.1	-9.3	-8.7
01-Jan-2015 - 31-Mar-2015	9.74	1.6	1.6
Average	**10.19**	**-4.0**	**-4.2**

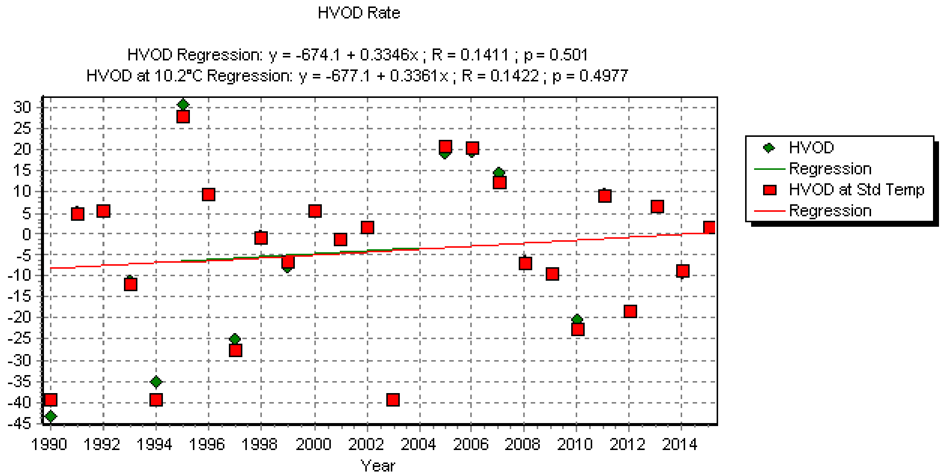
HVOD Analysis

Lake: LAKE ROTORANGI

Stations: L2 (Tangahoe Valley Rd)

Date From: 01/01/1990 **Date To:** 31/12/2015

Analysis Period	Average	Observed DO	Observed Rate Corrected to 10.2 °C (mg/m3/day)



LAKE ROTORANGI

L2 1990-2015 (1 Jan 1990 - 31 Dec 2015)

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)	(0.01)	(0.13)	(0.34)			
Average Over Period	3.14	(2.63)	(29.58)	(628.63)	(-4.17)			
Percent Annual Change (%/Year)	**2.23**	**0.00**	**0.00**	**0.00**	**0.00**	**0.45**	**0.45**	**0.37**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Jan 1990 - Dec 1990	7.20	1.25	25.00	840.00	4.40	5.27	4.30	5.19	4.79	0.26			
Jan 1991 - Dec 1991	2.17	2.34	19.50	610.00	3.08	4.53	3.98	4.77	4.09	0.38			
Jan 1992 - Dec 1992	3.07	1.92	18.33	350.00	3.46	4.77	3.91	4.05	4.04	0.27			
Jan 1993 - Dec 1993	2.47	3.82	15.00	233.33	3.22	3.93	3.65	3.52	3.58	0.15			
Jan 1994 - Dec 1994	1.33	2.29	34.25	655.00	2.53	4.56	4.70	4.87	4.16	0.55			
Jan 1995 - Dec 1995	2.23	2.71	31.33	373.33	3.11	4.35	4.59	4.13	4.04	0.33			
Jan 1996 - Dec 1996	3.08	2.52	26.00	570.00	3.46	4.44	4.35	4.69	4.23	0.27			
Jan 1997 - Dec 1997	1.32	2.35	20.50	570.00	2.53	4.53	4.05	4.69	3.95	0.49			
Jan 1998 - Dec 1998	2.15	2.06	66.00	675.00	3.06	4.68	5.53	4.91	4.55	0.53			
Jan 1999 - Dec 1999	2.74	3.77	31.80	648.00	3.33	3.95	4.61	4.85	4.18	0.34			
Jan 2000 - Dec 2000	3.85	2.57	22.75	830.00	3.71	4.42	4.18	5.18	4.37	0.31			
Jan 2001 - Dec 2001	2.43	3.87	13.00	745.00	3.20	3.92	3.47	5.04	3.90	0.40			
Jan 2002 - Dec 2002	3.15	2.14	32.50	982.50	3.49	4.64	4.63	5.40	4.54	0.39			
Jan 2003 - Dec 2003	1.77	2.98	21.25	617.50	2.85	4.24	4.09	4.79	3.99	0.41			
Jan 2004 - Dec 2004	3.17	0.93	67.75	972.50	3.49	5.62	5.56	5.38	5.02	0.51			
Jan 2005 - Dec 2005	3.30	2.50	24.00	590.00	3.54	4.45	4.25	4.73	4.24	0.25			
Jan 2006 - Dec 2006	2.50	2.55	17.50	490.00	3.23	4.43	3.85	4.49	4.00	0.29			
Jan 2007 - Dec 2007	5.27	2.34	28.17	730.00	4.05	4.53	4.45	5.01	4.51	0.20			
Jan 2008 - Dec 2008	2.15	3.01	21.67	626.67	3.06	4.23	4.12	4.81	4.05	0.36			
Jan 2009 - Dec 2009	4.38	3.30	19.17	636.67	3.85	4.11	3.96	4.83	4.19	0.22			
Jan 2010 - Dec 2010	4.32	2.21	26.33	740.00	3.84	4.60	4.37	5.03	4.46	0.25			
Jan 2011 - Dec 2011	3.50	3.87	46.17	768.33	3.60	3.92	5.08	5.08	4.42	0.39			
Jan 2012 - Dec 2012	2.90	2.16	43.00	638.33	3.39	4.63	4.99	4.83	4.46	0.36			
Jan 2013 - Dec 2013	6.35	2.91	34.50	280.00	4.26	4.27	4.71	3.76	4.25	0.19			
Jan 2014 - Dec 2014	3.97	3.06	18.67	393.33	3.74	4.21	3.93	4.20	4.02	0.11			
Jan 2015 - Dec 2015	5.50	2.16	25.50	225.00	4.10	4.63	4.33	3.47	4.13	0.25			
Averages	**3.32**	**2.60**	**28.83**	**607.33**	**3.45**	**4.46**	**4.37**	**4.68**	**4.24**	**0.07**	**0.00**	**0.01**	**0.5744**

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 = 0.45 ± 0.45 % per year
P-Value = 0.37

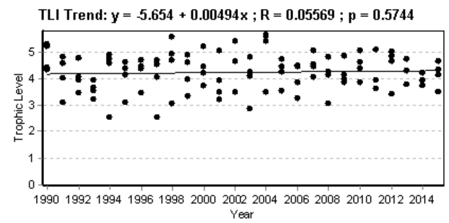
TLI Value = 4.24 ± 0.07 TLI units
TLI Trend = 0.00 ± 0.01 TLI units per year
P-Value = 0.5744

ASSESSMENT:

Eutrophic
No Change

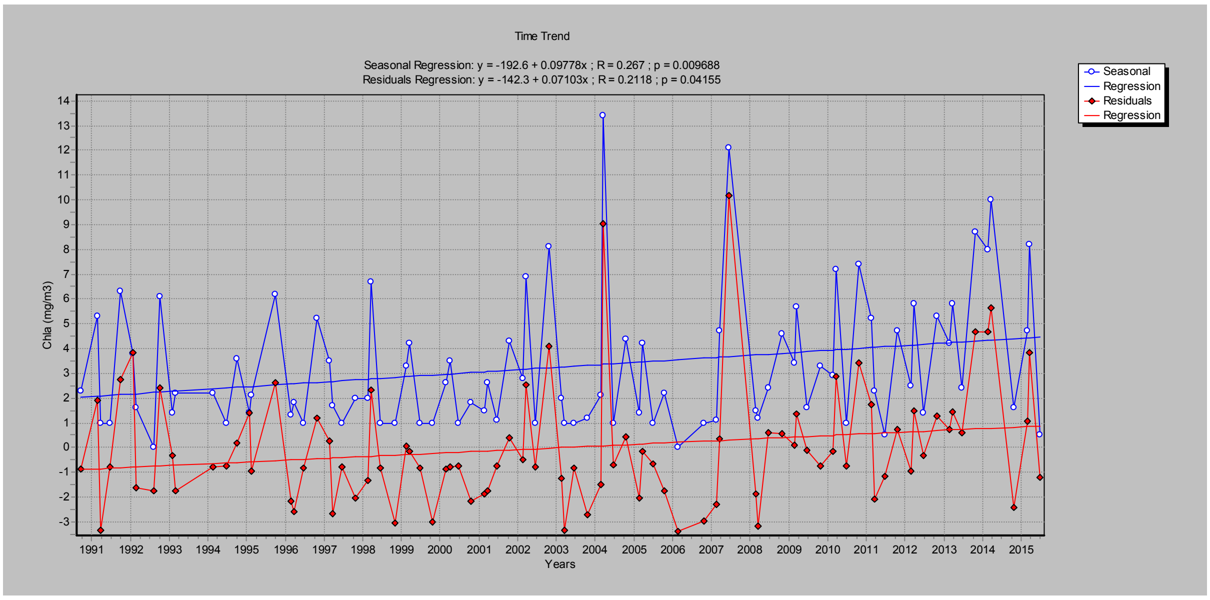
The guide used in the PAC average P-Value evaluation is

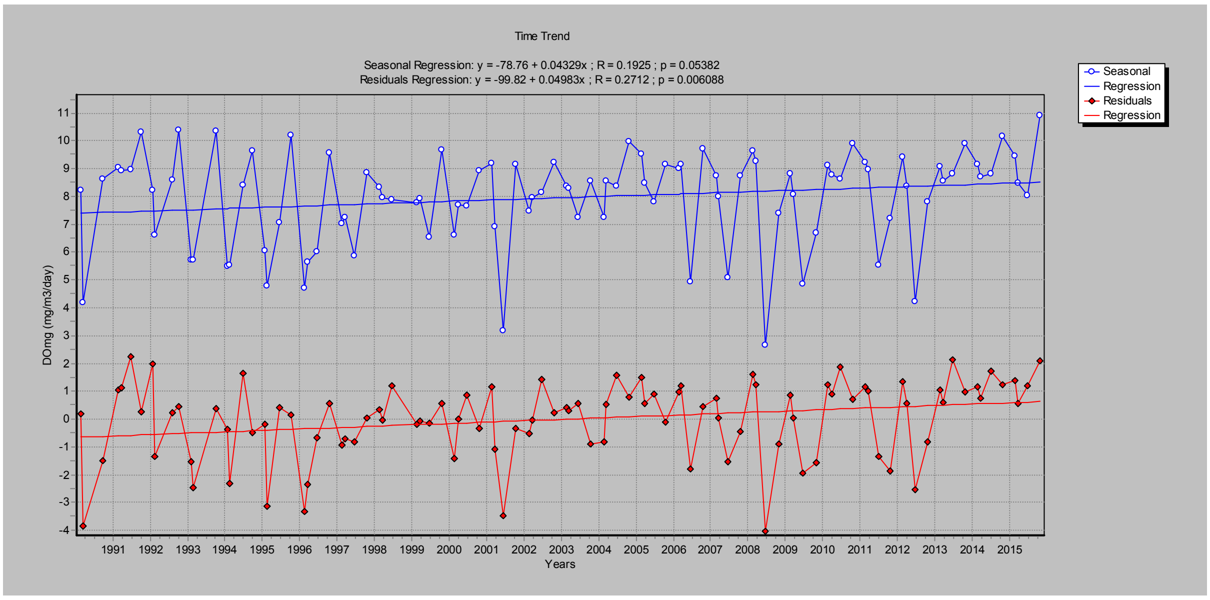
P-Value Range	Interpretation
P ≤ 0.1	Definite Change
0.1 < P ≤ 0.2	Probable Change
0.2 < P ≤ 0.3	Possible Change
0.3 < P	No Change

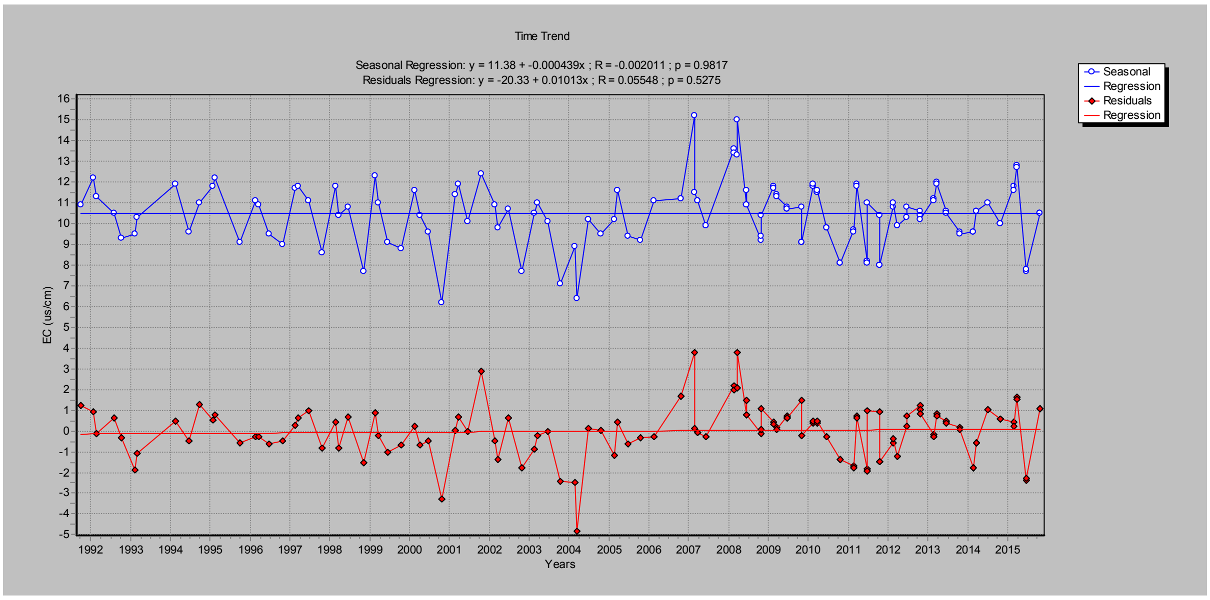


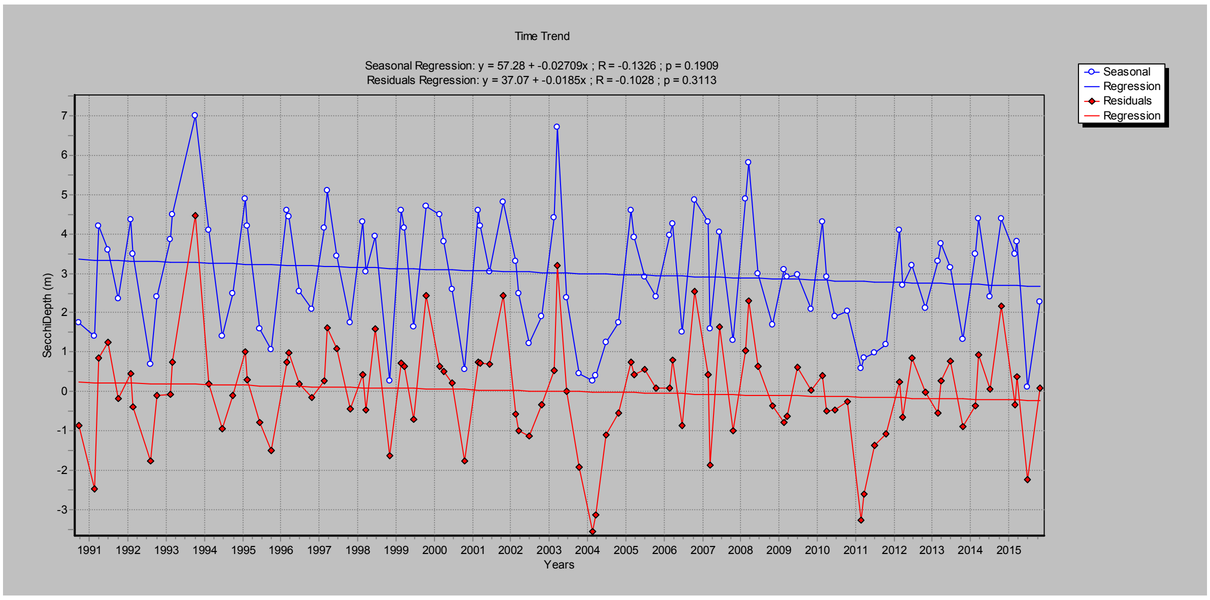
Appendix 4

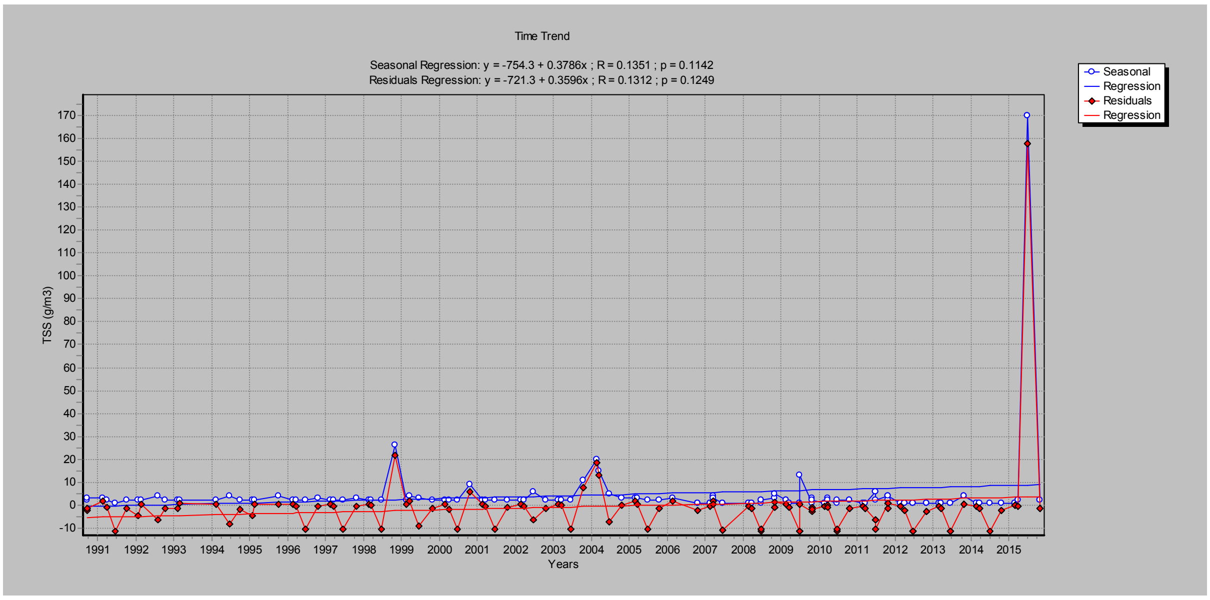
L3 – Physical parameters

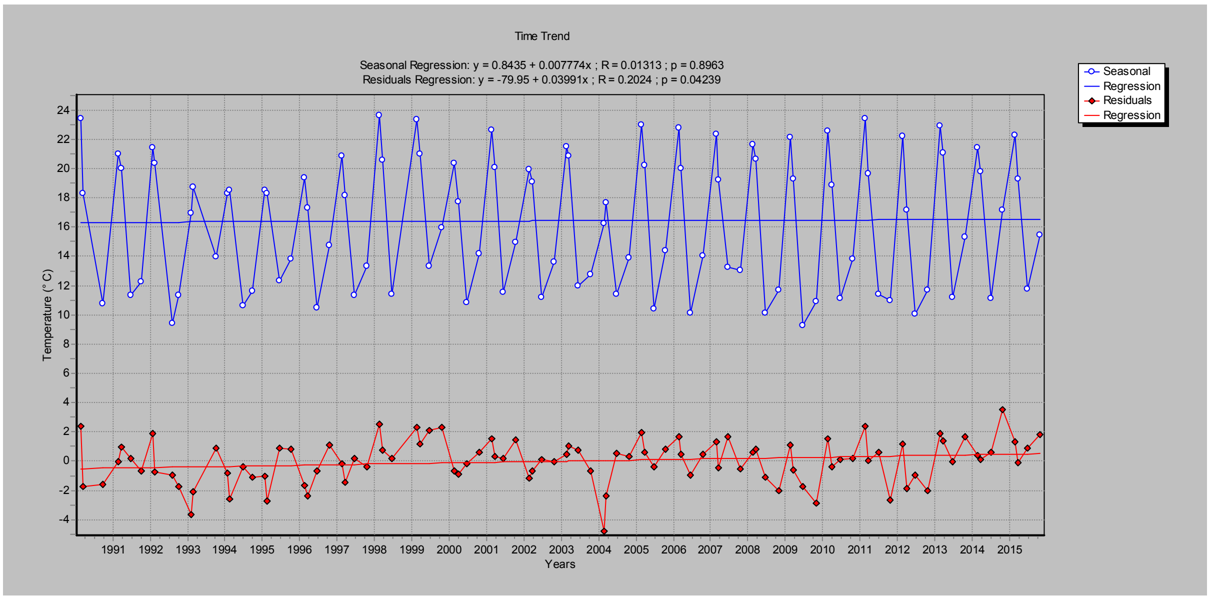




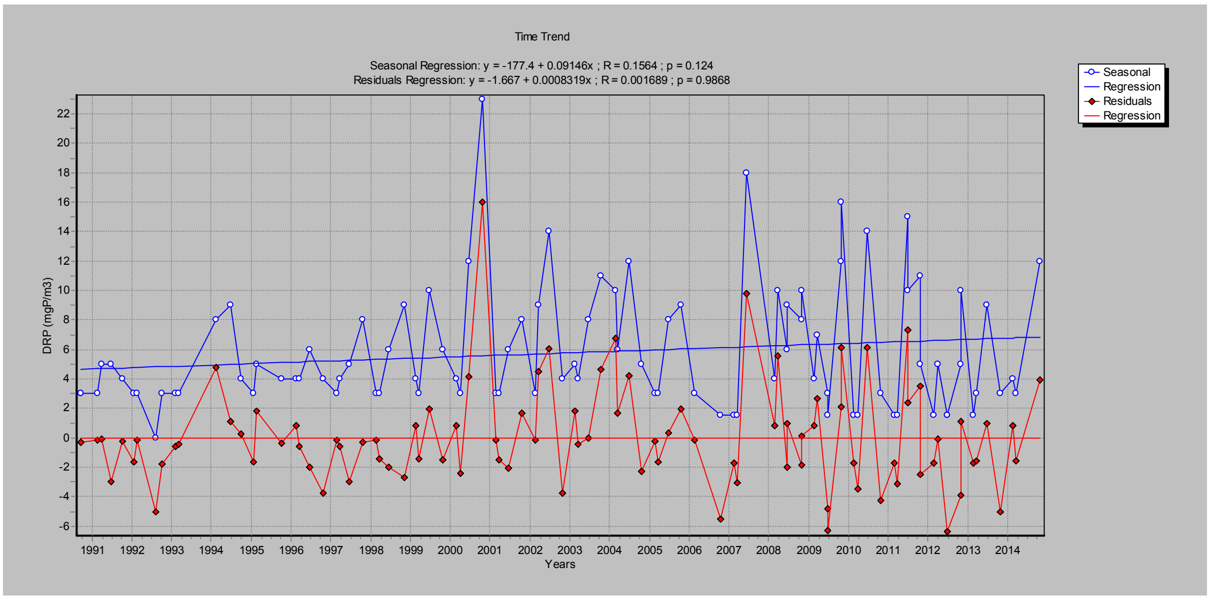

Time Trend
Seasonal Regression: y = 11.38 + -0.000439x ; R = -0.002011 ; p = 0.9817
Residuals Regression: y = -20.33 + 0.01013x ; R = 0.05548 ; p = 0.5275
Seasonal
Regression
Residuals
Regression
EC (us/cm)
Years

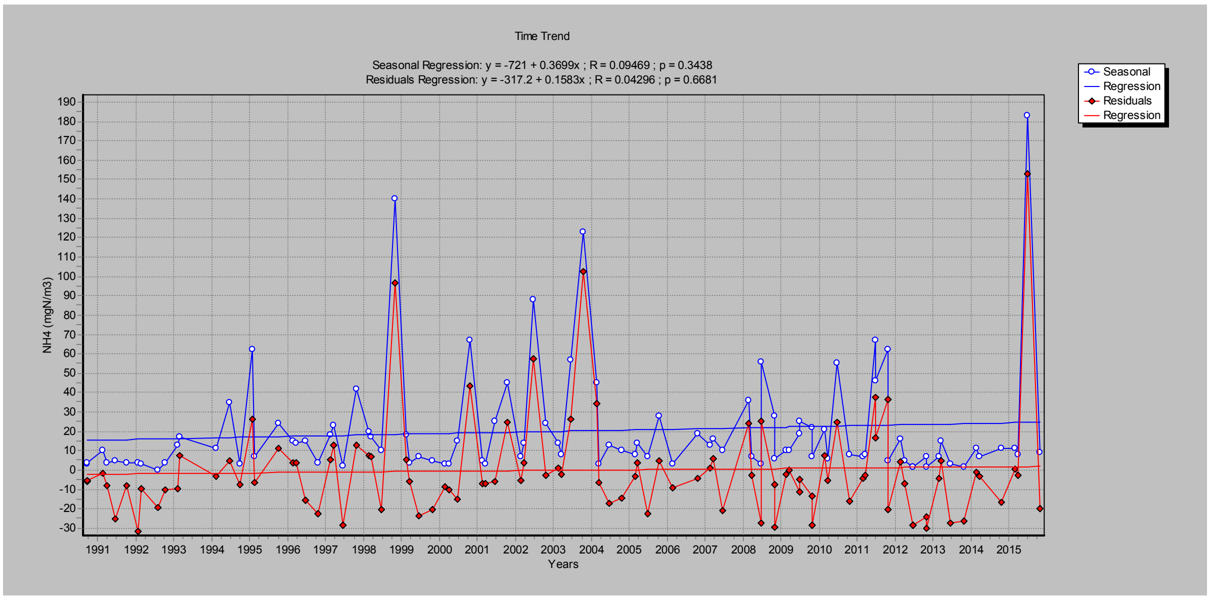

Time Trend
Seasonal Regression: y = 57.28 + -0.02709x ; R = -0.1326 ; p = 0.1909
Residuals Regression: y = 37.07 + -0.0185x ; R = -0.1028 ; p = 0.3113
Seasonal
Regression
Residuals
Regression
SecchiDepth (m)
Years

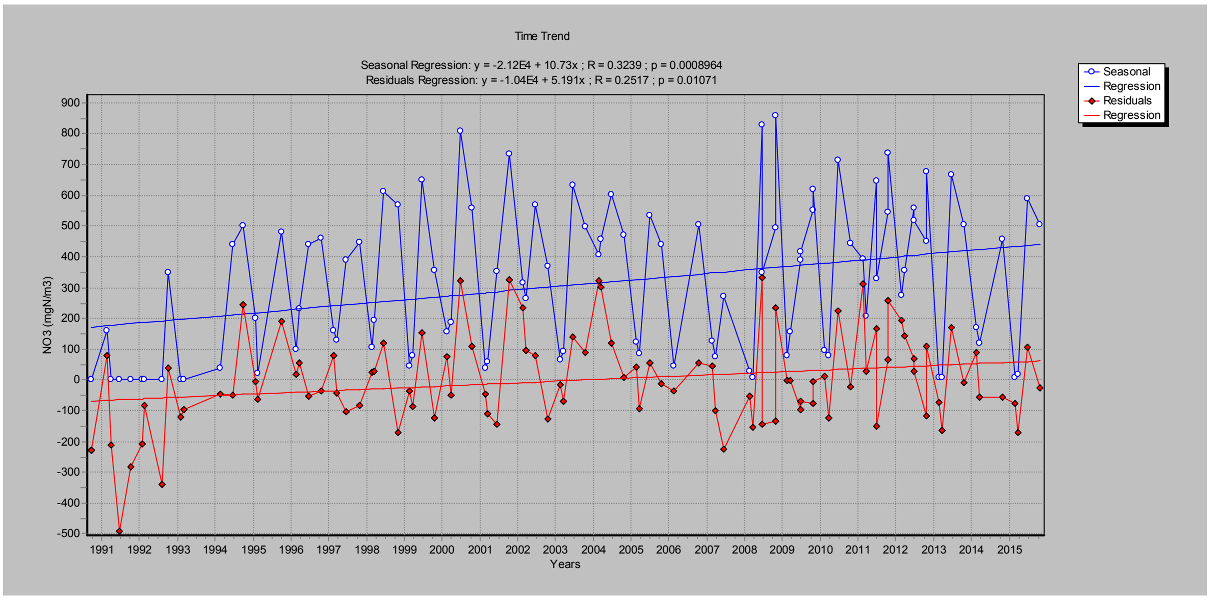

Time Trend
Seasonal Regression: y = -754.3 + 0.3786x ; R = 0.1351 ; p = 0.1142
Residuals Regression: y = -721.3 + 0.3596x ; R = 0.1312 ; p = 0.1249
TSS (g/m3)
Years
Seasonal
Regression
Residuals
Regression

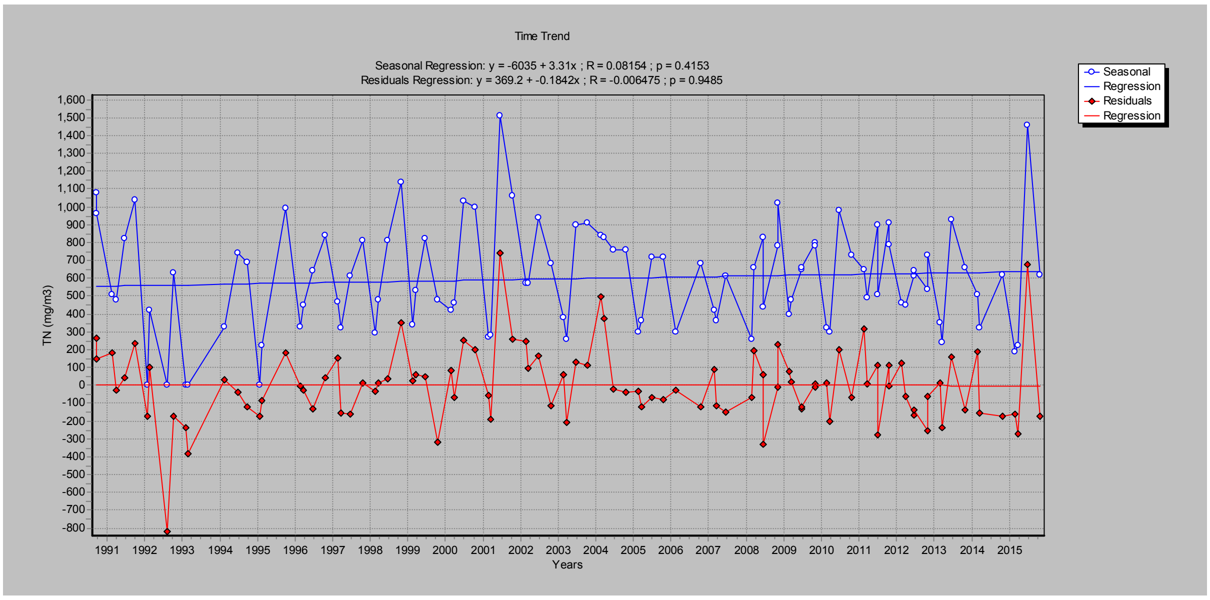

Time Trend
Seasonal Regression: y = 0.8435 + 0.007774x ; R = 0.01313 ; p = 0.8963
Residuals Regression: y = -79.95 + 0.03991x ; R = 0.2024 ; p = 0.04239
Temperature (° C)
Years
Seasonal
Regression
Residuals
Regression

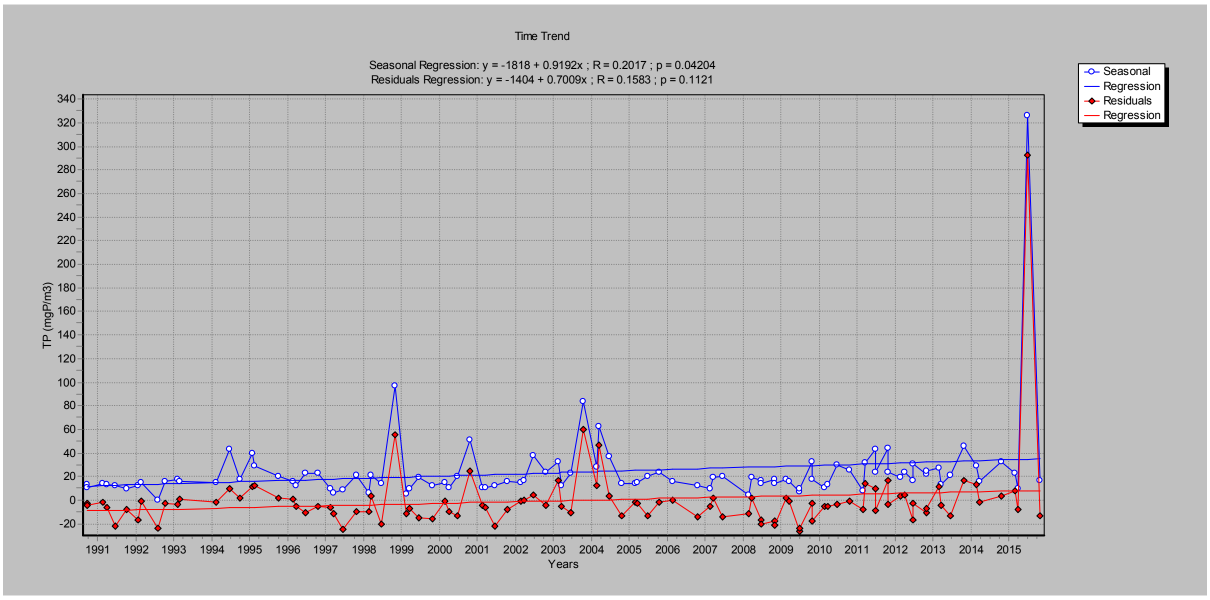
L3 - Nutrients






Time Trend
Seasonal Regression: y = -2.12E4 + 10.73x ; R = 0.3239 ; p = 0.0008964
Residuals Regression: y = -1.04E4 + 5.191x ; R = 0.2517 ; p = 0.01071
Seasonal
Regression
Residuals
Regression
NO3 (mgN/m3)
Years


Time Trend
Seasonal Regression: y = -6035 + 3.31x ; R = 0.08154 ; p = 0.4153
Residuals Regression: y = 369.2 + -0.1842x ; R = -0.006475 ; p = 0.9485
Seasonal
Regression
Residuals
Regression
TN (mg/m3)
Years



Time Trend
Seasonal Regression: y = -1818 + 0.9192x ; R = 0.2017 ; p = 0.04204
Residuals Regression: y = -1404 + 0.7009x ; R = 0.1583 ; p = 0.1121
Seasonal
Regression
Residuals
Regression
TP (mgP/m3)
Years

HVOD Analysis

Lake: LAKE ROTORANGI

Stations: L3 (Dam)

Date From: 01/01/1990 **Date To:** 31/12/2015

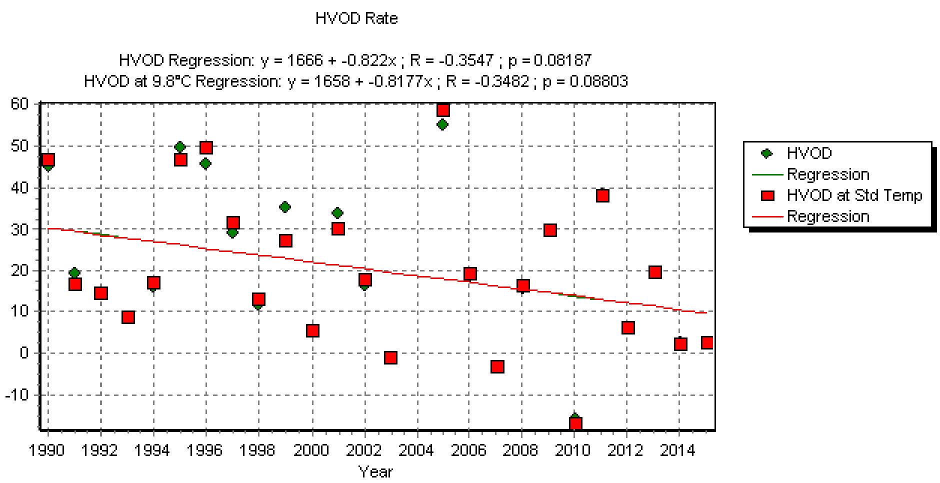
Analysis Period	Average	Observed DO	Observed Rate Corrected to 9.8 °C (mg/m3/day)
01-Jan-2000 - 04-Apr-2000	10.0	5.8	5.7
01-Jan-2001 - 31-Mar-2001	11.39	34.0	30.4
01-Jan-2002 - 31-Mar-2002	8.6	16.5	17.9
01-Jan-2003 - 31-Mar-2003	9.47	-0.8	-0.8
01-Jan-2005 - 31-Mar-2005	8.86	55.0	58.7
01-Jan-2006 - 31-Mar-2006	9.34	18.8	19.4
01-Jan-2007 - 31-Mar-2007	12.07	-3.1	-2.6
01-Jan-2008 - 30-Mar-2008	9.25	16.0	16.7
01-Jan-2009 - 31-Mar-2009	9.76	29.9	29.9
01-Jan-2010 - 31-Mar-2010	8.98	-15.6	-16.5
01-Jan-2011 - 31-Mar-2011	9.88	38.4	38.2
01-Jan-2012 - 30-Mar-2012	9.57	6.3	6.4
01-Jan-2013 - 31-Mar-2013	9.78	19.7	19.7
01-Jan-2014 - 31-Mar-2014	10.92	2.8	2.6
01-Jan-2015 - 31-Mar-2015	9.51	2.8	2.8
01-Jan-1990 - 31-Mar-1990	9.31	45.4	47.0
01-Jan-1991 - 31-Mar-1991	11.6	19.4	17.1
01-Jan-1992 - 30-Mar-1992	9.76	14.6	14.7
01-Jan-1993 - 31-Mar-1993	9.4	8.8	9.0
01-Jan-1994 - 31-Mar-1994	8.62	16.1	17.5
01-Jan-1995 - 31-Mar-1995	10.62	49.8	47.0
01-Jan-1996 - 30-Mar-1996	8.59	45.7	49.7
01-Jan-1997 - 31-Mar-1997	8.51	29.1	31.8
01-Jan-1998 - 31-Mar-1998	8.09	11.8	13.3
01-Jan-1999 - 31-Mar-1999	13.49	35.3	27.3
Average	**9.81**	**20.1**	**20.1**

HVOD Analysis

Lake: LAKE ROTORANGI
Stations: L3 (Dam)

Date From: 01/01/1990 **Date To:** 31/12/2015

Analysis Period	Average	Observed DO	Observed Rate Corrected to 9.8 °C (mg/m3/day)



LAKE ROTORANGI

L3 1990-2015 (1 Jan 1990 - 31 Dec 2015)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	0.08	(-0.02)	(0.01)	(-1.89)	(-0.80)			
Average Over Period	3.23	(3.01)	(20.50)	(585.54)	(20.12)			
Percent Annual Change (%/Year)	**2.48**	**0.00**	**0.00**	**0.00**	**0.00**	**0.50**	**0.50**	**0.37**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Jan 1990 - Dec 1990	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			
Jan 2013 - Dec 2013	5.00	2.88	20.00	295.00	4.00	4.28	4.02		4.10	0.09			
Jan 2014 - Dec 2014	9.00	3.68	22.50	415.00	4.64	3.98	4.17		4.26	0.20			
Jan 2015 - Dec 2015	6.45	2.42	16.67	343.33	4.28	4.49	3.79		4.18	0.21			
Averages	**3.32**	**3.00**	**20.37**	**566.60**	**3.39**	**4.30**	**3.95**		**3.88**	**0.07**	**0.02**	**0.01**	**0.0418**

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 = 0.50 ± 0.50 % per year
P-Value = 0.37

TLI Value = 3.88 ± 0.07 TLI units
TLI Trend = 0.02 ± 0.01 TLI units per year
P-Value = 0.0418

ASSESSMENT:

Mesotrophic
No Change

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

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

TLI Trend: y = -35.49 + 0.01966x ; R = 0.2311 ; p = 0.0418