State of the Environment Monitoring of Lake Rotorangi water quality and biological programme Annual Report 2014-2015

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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 for the lake, and this report presents the results of the twenty-fifth year of this monitoring.

Four water quality sampling surveys were performed at two sites during the 2014-2015 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. It should be noted that the fourth survey, undertaken in June 2015, followed severe flooding in the catchment. This markedly impacted on aspects of water clarity along the lake and contributed to more complete de-stratification (mixing) of the water column at this time.

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. The winter survey recorded no oxygen depletion at the mid site in winter, while only minimal depletion was noted at the lower lake site at this time. This is an a-typical result, and was caused by the significant flooding that preceded this survey. This resulted in lake overturn not being quite complete at the lower lake site by the time of the winter survey although water temperatures were uniform throughout the water column. Overturn was apparent at the mid lake site in winter.

During the monitoring year phytoplankton richnesses varied relatively widely from no taxa (following extensive winter flooding) to historical maximum richnesses at both sites (14 to 16 taxa) during the very dry summer-autumn period. These were coincident with very 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 this water quality data over time found a very slow rate of increase in trophic level. An update of the trend report (for the period 1990-2014) 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 2015-2016 monitoring year.

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

Annual SEM reports act as 'building blocks' towards the preparation of the regional state of the environment report every five years. The Council's first, or baseline, state of the environment report was prepared in 1996 (TRC, 1996a), summarising the region's progress in managing environmental quality in Taranaki over the past two decades. The second report (for the period 1995-2000) was published in 2003 (TRC, 2003a). The third State of the Environment report (for the period 1995 to 2007) was published in 2009 (TRC, 2009a) and included trend reporting. The fourth report (for the period 1995 to 2013) has recently been published (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 intermediary zone is known as the metalimnion. The characteristics of lakes and the importance of nutrients and eutrophication were fully discussed in the Taranaki Catchment Board (1988) report.

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

Following the publication of the initial monitoring report, the 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-two 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 tropic condition in the lake (Burns, 1995). An additional review of the results of the ten years of monitoring was undertaken by Lakes Consultancy (Burns, 1999), who also assessed the trophic status of Lake Rotorangi (see Section 1.4). Lake water quality trends for the period 1990–2006 were also re-analysed by Lakes Consultancy (Burns, 2006) as a component of a consent renewal process which was progressed during the 2007-2010 period. The Council has subsequently re-analysed the water quality trends over the 1990-2014 period and will continue to update these trends at regular intervals.

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

As at June 2015, some 195 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 825 km of Patea riverbank [67% of the total banks' length] and 17 km of Mangaehu stream banks [42%] currently have adequate riparian protection provided on the properties covered by the plans. This represents an increase of 52 km in the Patea catchment and 5 km in the Mangaehu catchment over the past year. Outside of the properties covered by plans there are a further 52% and 98% of streambanks in the Patea and Mangaehu catchments respectively, with only some (natural) degree of riparian protection, or landowner fencing/planting that is not covered by a Council prepared plan. No riparian plans have, as yet, been prepared for properties in these reaches. Within the Patea River sub-catchment, the areas where there is an absence of riparian plans are located to the northeast and south east of the catchment, and comprise run-off or sheep and beef grazing properties rather than dairy farms. The Mangaehu catchment is predominantly hill-country grazing rather than dairy country.

1.3 Trends in lake water quality

As referenced in Section 1.2, 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 23 year period 1990-2014 (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) and it notes that there are some insignificant increases in the average concentrations of key variables (secchi disc visibility, total phosphorus, and total nitrogen), with significant temporal increases in nitrate nitrogen and chlorophyll-a and an insignificant improvement in suspended solids.

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 2014, 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 2014-2015 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]
- dissolved oxygen	X	X
- secchi disc transparency	X	X
- black disc transparency	X	X
- conductivity	X	X
- turbidity	X	X
- suspended solids	X	X
- chlorophyll-a[3]	X	X
(b) Epilimnion, for:	[LRT00E300]	[LRT00E450]
- suspended solids	X	X
- total phosphorus	X	X
- dissolved reactive phosphorus	X	X
- nitrate-nitrogen	X	X
- ammoniacal-nitrogen	X	X
- pH	X	X
- conductivity	X	X
(c) Hypolimnion, for:	[LRT00H300]	[LRT00H450]
- total phosphorus	X	X
- dissolved reactive phosphorus	X	X
- nitrate-nitrogen	X	X
- ammoniacal-nitrogen	X	X
- total Kjeldahl nitrogen	X	X
- pH	X	X
- conductivity	X	X
(d) Sediment/water/interface[4]	[LRT00B300]	[LRT00B450]
- ammoniacal-nitrogen	X	X
- total phosphorus	X	X
- dissolved reactive phosphorus	X	X
- nitrite and nitrate nitrogen	X	X

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

Figure 1 Aerial location map of Lake Rotorangi water quality sampling sites for 2014-2015 [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	22 October 2014
2	Late summer, stratification	24 February 2015
3	Autumn, stratification	23 March 2015
4	Winter	25 June 2015

Photo 1 Survey conditions, 25 June 2015 at Hawera Waterski Club jetty near site L2

Photo 2 Debris in lake at Patea dam, near site L3, 25 June 2015

The spring sampling survey was performed under steady flood recession river flow conditions following a small fresh four days earlier and four other river freshes over the preceding one month (see Figures 2 and 3 and Appendix I). The late summer survey occurred under very low river recession flow conditions following one small fresh three weeks earlier. The autumn survey was performed under steady fresh recession flow conditions two weeks since the previous fresh. The final (winter) survey was performed during flood river recession flow conditions four days after very significant river flooding (see Photos 1 and 2), and after a wet period of nine freshes in both catchments over the preceding six weeks. Lake level was moderate (75.9 m asl) at the time of the spring survey, very high during the winter survey (77.8 m asl), and moderate (76.1 m asl) during the late summer and the autumn surveys (76.4 m asl).

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

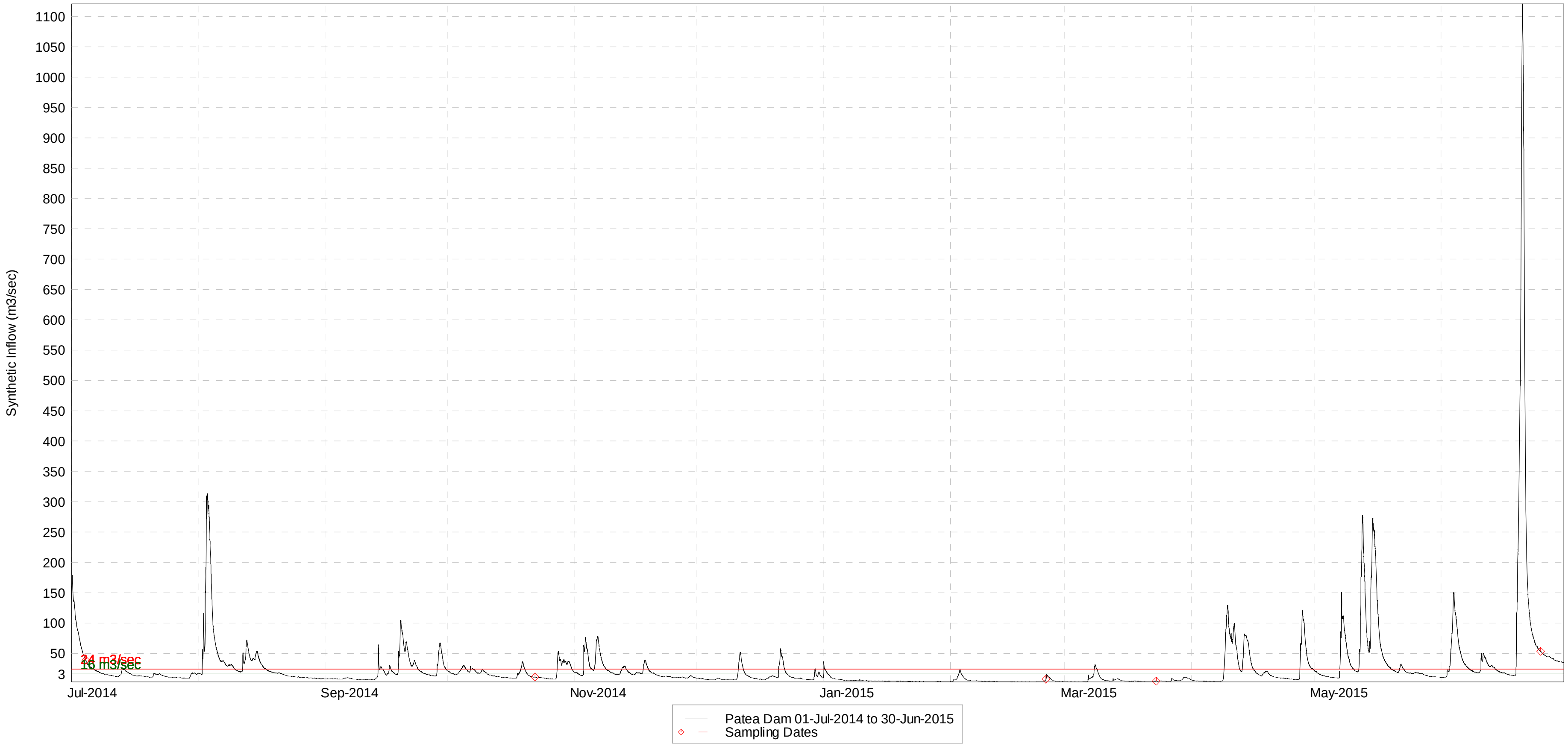


Figure 2 Synthesized hourly mean inflow at Lake Rotorangi for the period 1 July 2014 to 30 June 2015

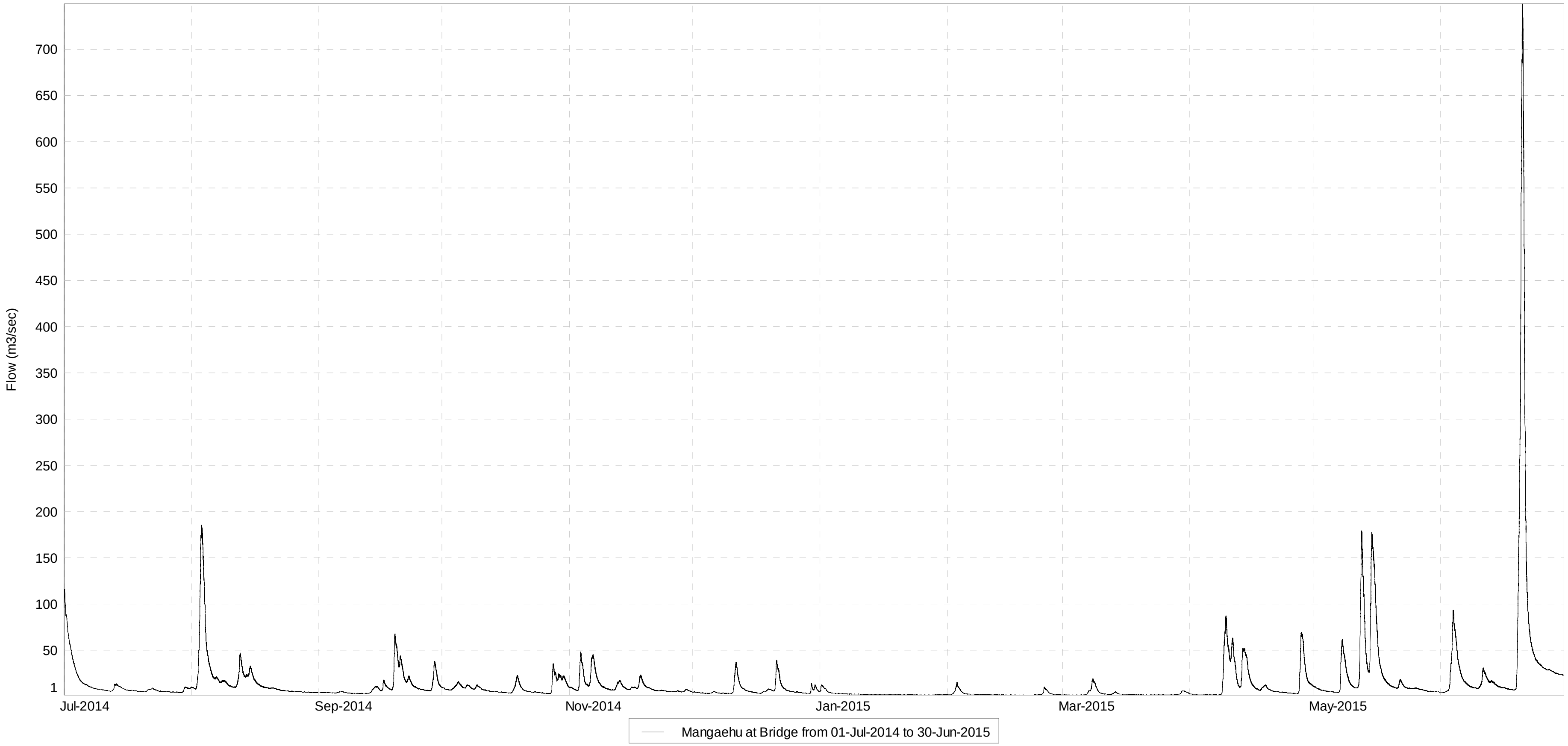


Figure 3 Flow in the Mangaehu River from July 2014 to June 2015

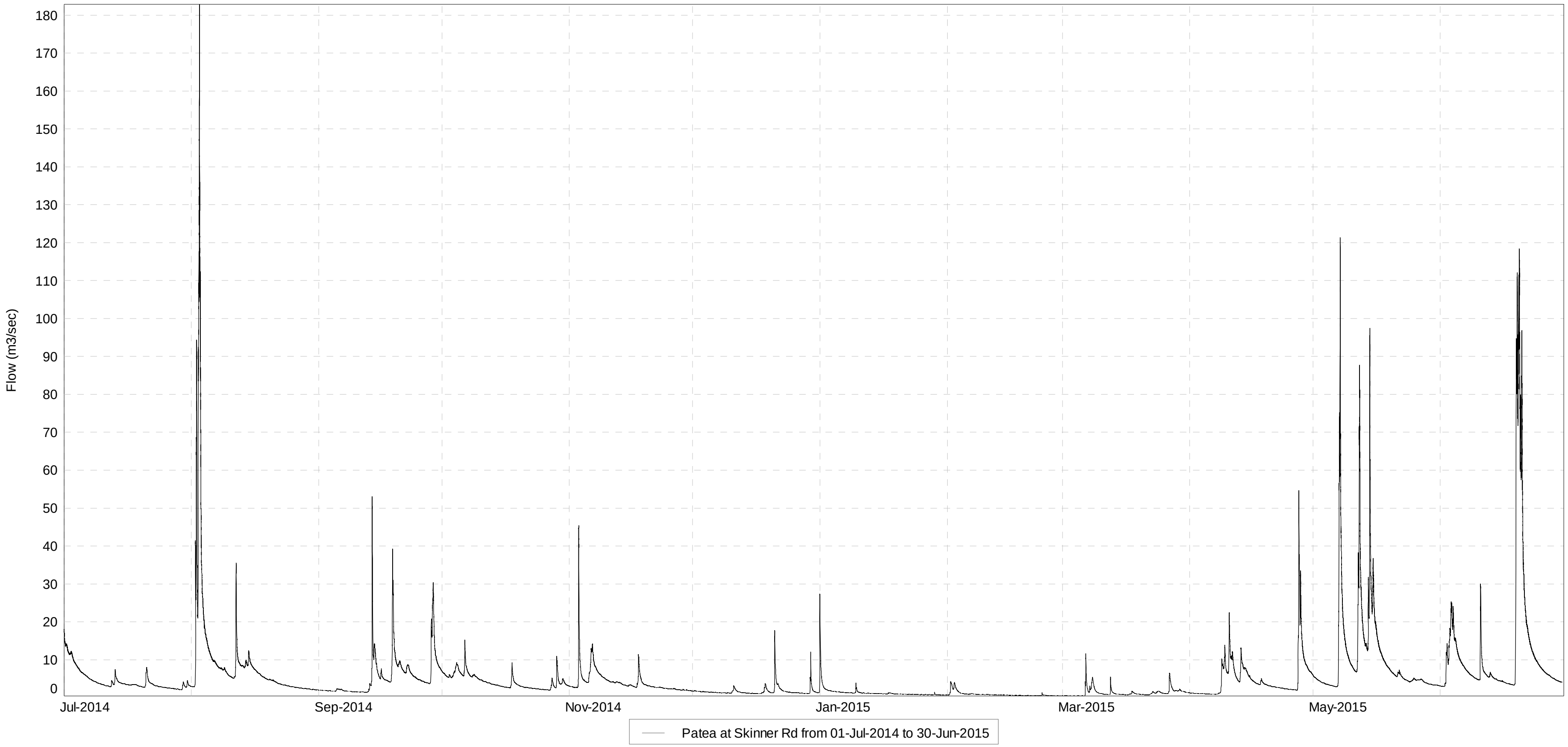


Figure 4 Flow in the Patea River at Skinner Road from July 2014 to June 2015

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 2014-2015

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	22.10.14	1000-1100	Clear, fine	Light	18.5	16.9	Clear, midgreen surface ripple; no debris	3.05	2.42	36
	24.02.15	0915-1025	Overcast, fine	Calm	19.0	22.0	Clear, dark green-grey; surface flat; no debris	3.54	2.40	38
	23.03.15	0905-1025	Overcast, fine	Calm	21.5	19.4	Clear, dark green-grey; surface ripple; no debris	3.55	2.72	38
	25.06.15	1130-1230	Overcast, fine	Calm	9.0	11.3	Turbid, brown; surface flat; debris common	0.09	0.09	27
L3	22.10.14	1150-1250	Clear, fine	Calm	21.0	18.3	Clear, pale green; surface ripple; no debris	4.40	3.90	46
	24.02.15	1105-1240	Overcast, fine	Calm	23.0	22.6	Clear, dark grey- green; surface ripple; no debris	3.50	2.80	44
	23.03.15	1055-1155	Partly cloudy, fine	Light	21.5	19.4	Clear dark green-grey; surface ripple; no debris	3.80	2.90	44
	25.06.15	1400-1500	Partly cloudy, fine	Calm	14.0	11.7	Turbid, brown; surface flat; debris common	0.12	0.12	32

[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 July 2014

Location	Parameter	Unit	Minimum	Maximum	Median	N
L2 surface	Temperature	°C	9.4	23.9	16.9	95
L3 surface	Temperature	°C	9.5	24.6	17.5	95

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 2014-2015 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 (°C) of surface and bottom waters at each Lake Rotorangi site (October 2014 to June 2015)

Sites	L2		L3	
Date	Surface	Bottom	Surface	Bottom
October 2014	16.9 (14.6)	9.3 (8.9)	18.3 (14.7)	9.3 (8.7)
February 2015	22.0 (21.8)	9.5 (9.7)	22.6 (22.1)	9.4 (9.4)
March 2015	19.4 (19.4)	9.5 (9.8)	19.4 (19.8)	9.4 (9.6)
June 2015	11.3 (11.2)	12.0 (9.3)	11.7 (11.3)	12.3 (9.4)

Note: *( ) = average monthly temperature for period 1984 to mid-2014*

All surface water temperatures at both sites were within past ranges measured at these sites (Table 4). Temperatures were within 0.1 ˚C to 2.3 ˚C of past monthly average temperatures at site L2 and 0.4 ˚C to 3.6 ˚C at site L3, at the time of all surveys. Bottom water temperatures at both sites were atypically higher than surface water temperatures by 0.6 ˚C to 0.7 ˚C (winter) but lower by nearly 13 °C (late summer) and within 0 ˚C to 0.6 ˚C of corresponding monthly average temperatures throughout most of the year. These two sites' bottom water temperatures (9.3 °C to 9.5 °C and 9.3 ˚C to 9.4 ˚C) showed a very narrow range (0.1 to 0.2 °C), due to minimal mixing through most of the year with the exception of post extensive flooding in June 2015 when bottom water temperatures rose after mixing. Surface water temperature ranges were much wider (10.7 °C [L2] to 10.9 °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 2014 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 5 and 7 m below the lake surface at both sites. The occurrence of many significant freshes between mid May and the winter June 2015 survey, and cooling of epilimnetic waters, contributed to the complete destruction of temperature stratification at these sites by the time of the June 2015 survey, although partial dissolved oxygen stratification remained at site L3 at this time (see section 3.1.2).

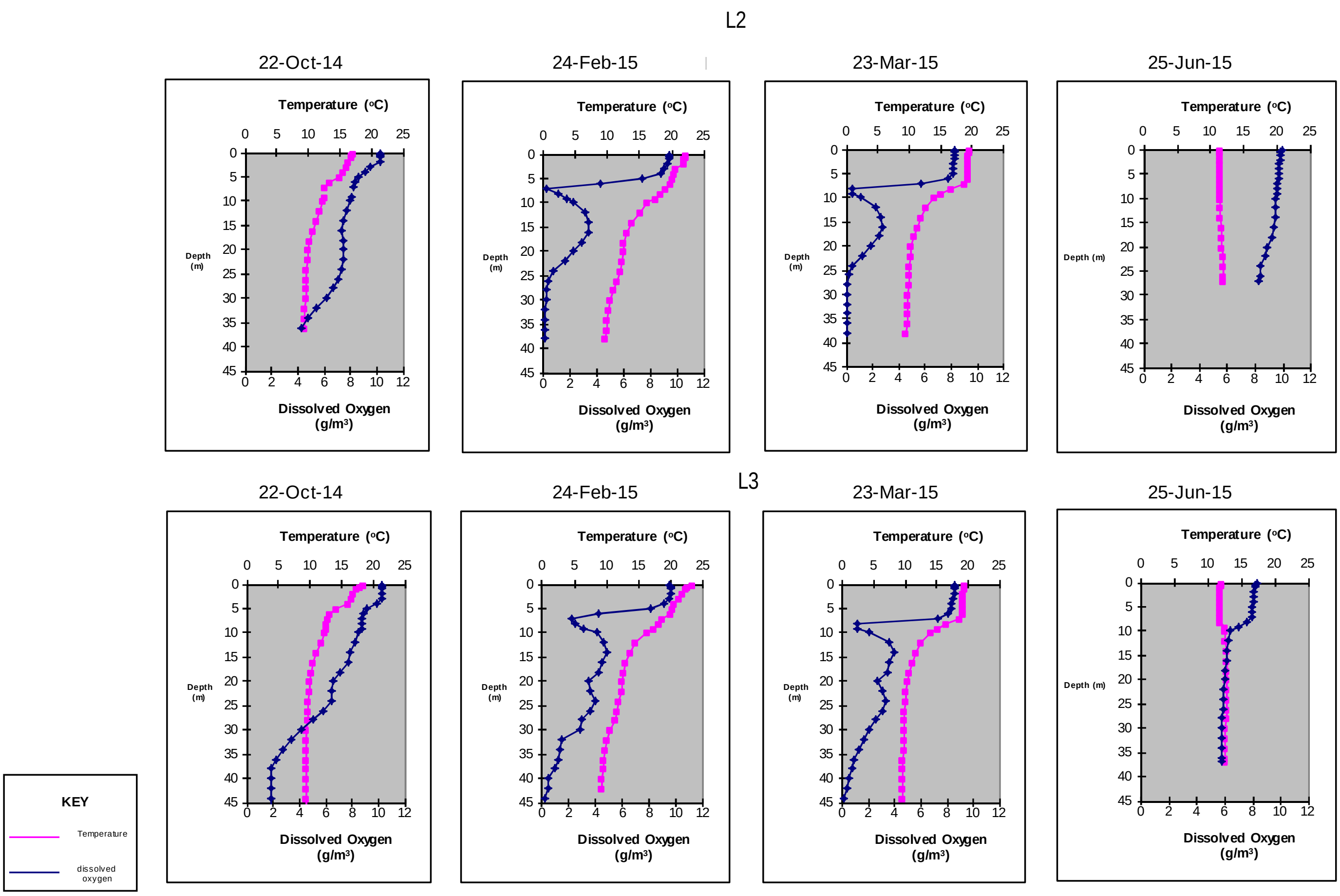


Figure 5 Temperature (˚C) and dissolved oxygen (g/m^3) profiles for site L2 and L3

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 July 2014

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

Table 7 Temporal changes in percentage dissolved oxygen saturation in surface and bottom waters at each Lake Rotorangi site (October 2014 to June 2015)

Sites	L2		L3	
Date	Surface	Bottom	Surface	Bottom
October 2014	106 (93)	37 (28)	108 (96)	15 (34)
February 2015	108 (98)	1 (2)	111 (101)	2 (7)
March 2015	90 (92)	1 (4)	94 (93)	1 (7)
June 2015	91 (80)	76 (55)	77 (63)	54 (12)

Note: ( ) = average monthly saturation for period 1984 to mid-2014

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 12% of total saturation with the exception of the winter, partial overturn level which fell to 77% saturation at site L3. Almost complete 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 2015 as indicated by the decrease in percentage saturation to well below 100% saturation. Late summer levels indicated supersaturation (108% to 111%) 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.

Total dissolved oxygen depletion was recorded within the hypolimnion during the February and March 2015 surveys at the mid lake site (L2) while the lower lake site L3 did not record total depletion throughout the hypolimnion at these times but showed almost total depletion below a depth of 40 m, although not 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 (site L2) and 25 m (site L3). 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, and below 40 m at site L3.

Minimal dissolved oxygen stratification remained at site L3 at the time of the winter survey in the absence of thermal stratification, as a result of extensive prior flooding through the lake, a dissimilar situation to that recorded at site L3 in twenty of the previous twenty-one 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 32 m to 38 m in depth (Figure 5). There was virtually no oxygen depletion at site L2 in winter, indicative of complete lake mixing, with levels of more than 8 g/m^3 recorded through the lake's depth.

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 deoxygenating rate, or the surveys were performed outside of summer months.

Burns (1995) noted that the average hypolimnion temperature often decreased with time which is the opposite type of change to that seen in most lakes. It means that it is not possible to calculate the re-oxygenation which occurs when hypolimnion of the lake is warmed by the downward mixing of thermocline water. This observed drop in the hypolimnion temperature may have been due to the inflow of cooler water into the top levels of the hypolimnion or may have been the result of the hypolimnetic withdrawal of water for power generation, although the latter is relatively unlikely. The observation of decreasing hypolimnion temperatures indicates that the water mass being monitored has changed, and this largely invalidates any reliable calculation of dissolved oxygen depletion rates. Further, it was noted that dissolved oxygen values close to the lake bottom were often near zero in February and March, which again weakened the value of calculated oxygen depletion rates. Also depletion rates should not be calculated when oxygen concentrations drop below 2 g/m^3 because depletion rates become concentration-dependent below this concentration (Burns 1995). Burns suggested that average hypolimnetic dissolved oxygen concentrations for each site (L2 and L3) should be plotted on time trend graphs for each month (February and March) on an annual basis. These data have been re-calculated and are presented 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 July 2014

Location	Parameter	Unit	Minimum	Maximum	Median	N
L2 Surface	Secchi disc transparency	m	0.09	5.23	2.70	95
	Black disc transparency	m	0.09	4.50	2.20	87
	Turbidity	NTU	0.4	80	2.0	80
	Suspended solids	NTU	<2	83	2	88
	Conductivity @ 20°C	g/m³	5.4	15.0	10.8	75
L2 Epilimnion	Turbidity	mS/m	0.6	90	2.2	85
	Suspended solids	g/m³	<2	81	2	92
	Conductivity @ 20°C	mS/m	5.3	14.5	11.0	89
L2 Hypolimnion	Turbidity	NTU	1.6	230	5.1	88
	Suspended solids	g/m³	<2	310	3	93
	Conductivity @ 20°C	mS/m	7.8	13.5	10.7	91
L3 Surface	Secchi disc transparency	m	0.26	7.00	3.14	95
	Black disc transparency	m	0.23	5.25	2.68	82
	Turbidity	NTU	0.5	30	1.4	82
	Suspended solids	g/m³	<2	25	<2	89
	Conductivity @ 20°C	mS/m	6.2	15.2	10.6	78
L3 Epilimnion	Turbidity	NTU	0.5	31	1.6	85
	Suspended solids	g/m³	<2	26	2	93
	Conductivity @ 20°C	mS/m	6.2	15.0	10.6	89
L3 Hypolimnion	Turbidity	NTU	0.8	77	3.0	87
	Suspended solids	g/m³	<2	92	<2	95
	Conductivity @ 20°C	mS/m	6.2	12.4	10.3	91

Data recorded from each site during the 2014-2015 year (Table 9) were within ranges of previous results for the first three surveys during the period, but results from the mid-winter post flood survey exceeded previous maximum values for suspended solids and turbidity at several sites and were below or similar to historical minima for conductivity and secchi disc transparency at some sites.

The recent floods prior to the winter sampling survey in particular caused marked elevation in turbidity levels and reduced the secchi disc clarity recorded at both surface sites (Photo 3).

Photo 3 Mid-winter 2015 flooding effects in Lake Rotorangi between sites L2 and L3

Table 9 Physical water quality monitoring data for the two Lake Rotorangi sites in the 2014-2015 period

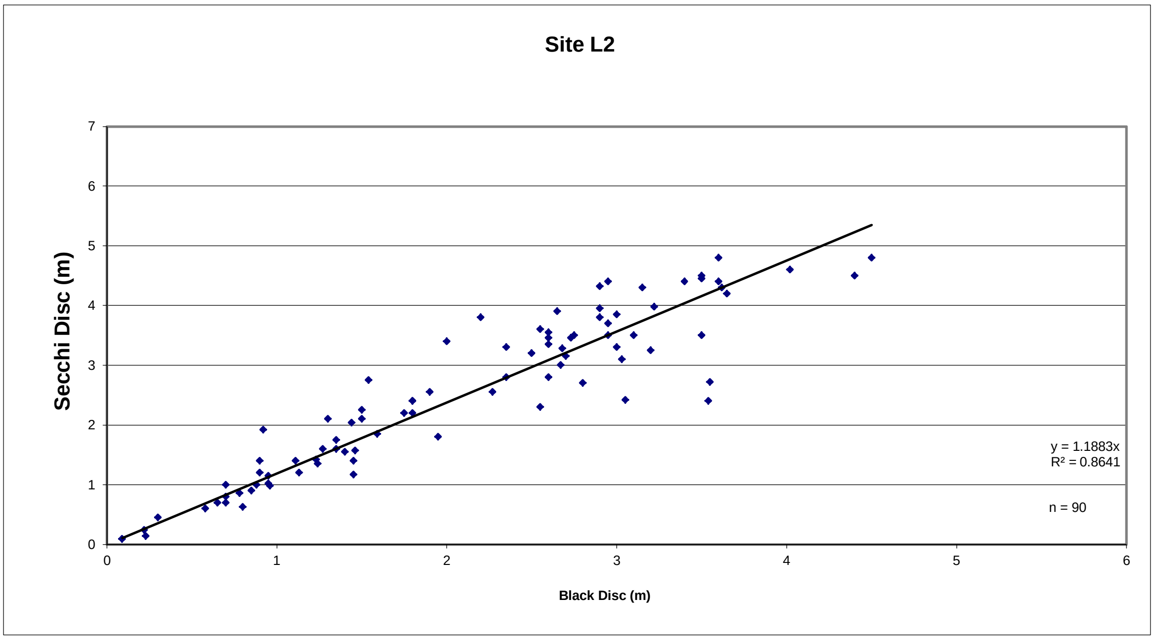
	Sites		L2			L3		
Date	Parameter	Unit	S	E	H	S	E	H
22.10.14	Secchi disc	m	3.05	-	-	4.40	-	-
	Turbidity	NTU	1.1	1.3	8.9	0.7	0.8	2.8
	Suspended solids	g/m³	<2	<2	8	<2	<2	<2
	Conductivity @ 20°C	mS/m	11.2	11.2	10.0	10.0	10.0	10.8
24.02.15	Secchi disc	m	3.54	-	-	3.50	-	-
	Turbidity	NTU	0.9	1.1	1.8	0.9	1.0	1.6
	Suspended solids	g/m³	<2	<2	<2	<2	<2	<2
	Conductivity @ 20°C	mS/m	14.0	14.0	11.0	11.6	11.8	10.9
23.03.15	Secchi disc	m	3.55	-	-	3.80	-	-
	Turbidity	NTU	0.8	0.9	1.9	1.1	1.0	1.3
	Suspended solids	g/m³	<2	<2	<2	2	<2	<2
	Conductivity @ 20°C	mS/m	14.7	14.5	11.2	12.8	12.7	11.5
25.06.15	Secchi disc	m	0.09	-	-	0.12	-	-
	Turbidity	NTU	240	250	510	250	250	780
	Suspended solids	g/m³	170	180	340	170	170	500
	Conductivity @ 20°C	mS/m	6.9	6.8	5.8	7.7	7.8	6.2
Range	Secchi disc	m	0.09-3.55	-	-	0.12-4.40	-	-
	Turbidity	NTU	0.8-240	0.9-250	1.8-510	0.7-250	0.8-250	1.3-780
	Suspended solids	g/m³	<2-170	<2-180	<2-340	<2-170	<2-170	<2-500
	Conductivity @ 20°C	mS/m	6.9-14.7	6.8-14.5	5.8-11.2	7.7-12.8	7.8-12.7	6.2-11.5

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

The impacts of relatively recent significant freshes resulted in very poor secchi disc clarity at sites L2 and L3 surface waters in winter with elevated turbidity and suspended solids levels through the water column at both sites (winter) and a slight elevation in these parameters in the site L2 hypolimnion in spring.

A narrower range of secchi disc transparency levels was recorded at site L2 (0.09 to 3.55 m) than site L3 (0.12 to 4.40 m) during the monitoring year. Marked impacts of river flooding upon lake clarity through the hypolimnion were recorded at site L3 in June 2015 due to severe flooding preceding this survey and to a greater extent than recorded historically. However equally poor surface water clarity and high suspended solids and turbidity levels were recorded at both sites on this survey occasion.

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



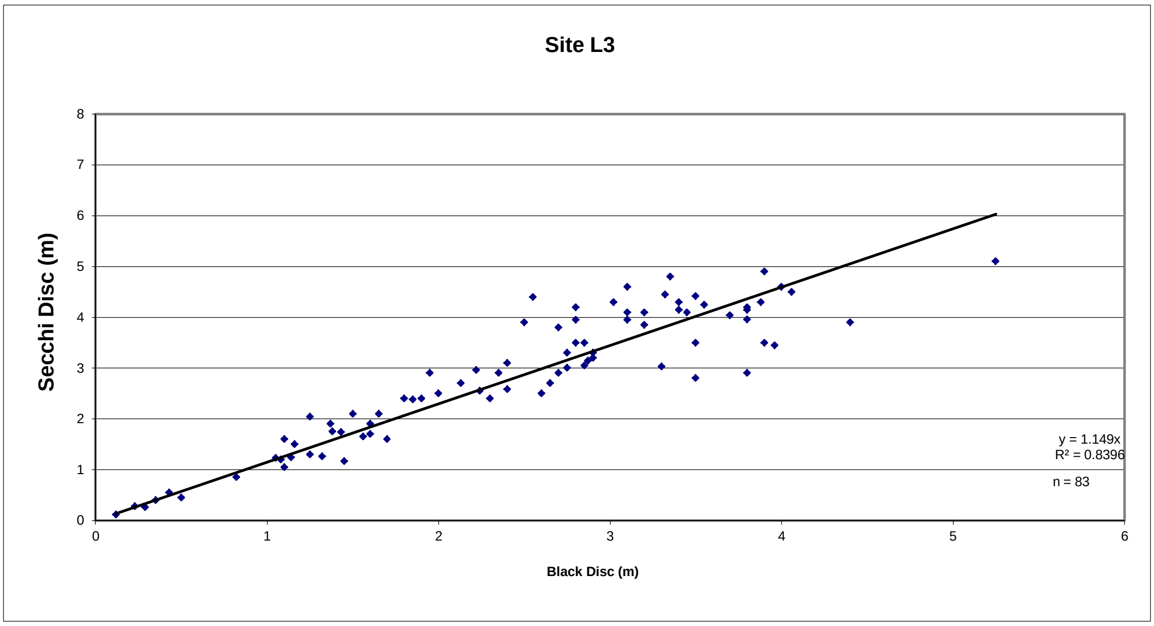


Figure 6 Relationship between secchi and black disc transparency at each sampling site

These trends have continued to be recorded during the most recent monitoring period under a moderate range of clarities. During the 2014-2015 monitoring period, black disc transparency ranges recorded at site L2 (0.09 to 2.72 m) were narrower than at site L3 (0.12 to 3.90 m) but never approached 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 July 2014

Location	Parameter	Unit	Minimum	Maximum	Median	Mean	N
L2 photic zone	Chlorophyll-a	mg/m³	<1.0	13.9	2.6	3.1	94
L3 photic zone	Chlorophyll-a	mg/m³	<1.0	13.4	2.2	3.2	94

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 (1984-2014)	Result 2014-15	Mean (1984-2014)	Result 2014-15
October 2014	3.5	3.9	3.9	1.6
February 2015	3.5	5.5	3.1	4.7
March 2015	3.9	5.5	4.2	8.2
June 2015	1.7	<1	1.5	<1
Range: 2014-2015	-	<1-5.5	-	<1-8.2
Range: 1984-2014	-	<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 2014)

	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

All chlorophyll-a concentrations measured at the two sites over the 2014-2015 period were within past ranges (Table 10) found by surveys since 1990.

Concentrations were well above historical median monthly values at both sites L2 and L3 in summer and autumn but below median monthly values at both sites in winter following severe flooding.

Maximum lake chlorophyll-a concentrations have tended to be measured during late summer or autumn at sites L2 and L3. Over the current period, the highest concentrations were found in the photic zone of the mid and lower lake in autumn when concentrations were above historical mean monthly results for both of these sites. All measured concentrations were within previous ranges recorded since 1984 at each site (Tables 11 and 12). The maximum chlorophyll-a concentration of 8.2 mg/m^3 was measured at lake site L3 during the autumn period and this was 2.7 mg/m^3 higher than the concentration found at site L2 in autumn.

Mean 2014 values at both sites were within historical values, although toward the maximum at site L3, for the sampling period from 1994 to 2013. 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 Tables 14 to 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 July 2014

Site	Parameter	Unit	Minimum	Maximum	Median	No. of samples
L2 Epilimnion	Dissolved reactive phosphorus	g/m³P	<0.003	0.018	0.005	93
	Total phosphorus	g/m³P	0.006	0.213	0.022	93
	Ammonia nitrogen	g/m³N	<0.003	0.370	0.020	93
	Nitrite	g/m³N	0.001	0.015	0.007	83
	Nitrate	g/m³N	<0.01	0.99	0.31	85
	Total Kjeldahl nitrogen	g/m³N	<0.01	1.20	0.27	90
	Total nitrogen	g/m³N	0.21	1.65	0.62	89
	pH		6.9	8.6	7.5	85
L2 Hypolimnion	Dissolved reactive phosphorus	g/m³P	<0.003	0.029	0.008	93
	Total phosphorus	g/m³P	0.011	0.22	0.022	93
	Ammonia nitrogen	g/m³N	<0.003	0.436	0.075	93
	Nitrite	g/m³N	<0.001	0.022	0.009	83
	Nitrate	g/m³N	0.02	0.93	0.48	87
	Total Kjeldahl nitrogen	g/m³N	<0.01	0.96	0.29	92
	Total nitrogen	g/m³N	0.45	1.50	0.78	92
	pH		6.5	7.4	6.9	86
L3 Epilimnion	Dissolved reactive phosphorus	g/m³P	<0.003	0.023	0.004	93
	Total phosphorus	g/m³P	0.004	0.097	0.018	93
	Ammonia nitrogen	g/m³N	<0.003	0.140	0.011	93
	Nitrite	g/m³N	<0.001	0.020	0.005	83
	Nitrate	g/m³N	<0.01	0.83	0.35	85
	Total Kjeldahl nitrogen	g/m³N	<0.01	1.15	0.27	90
	Total nitrogen	g/m³N	0.22	1.51	0.61	89
	pH		6.6	8.7	7.6	85
L3 Hypolimnion	Dissolved reactive phosphorus	g/m³P	<0.003	0.026	0.006	93
	Total phosphorus	g/m³P	0.005	0.196	0.017	93
	Ammonia nitrogen	g/m³N	<0.003	0.170	0.006	93
	Nitrite	g/m³N	<0.001	0.020	0.001	83
	Nitrate	g/m³N	0.05	1.00	0.54	87
	Total Kjeldahl nitrogen	g/m³N	<0.01	1.14	0.17	92
	Total nitrogen	g/m³N	0.30	1.78	0.73	92
	pH		6.5	7.2	6.8	87

Table 14 Nutrient water quality monitoring data for Lake Rotorangi site L2: Epilimnion (2014-2015)

Parameter		Date			
	Unit	22 Oct 2014	24 Feb 2015	23 Mar 2015	25 June 2015
Sample Depth	m	3	3	4	3
Dissolved Reactive Phosphorus	g/m³P	0.013	0.007	<0.003	0.006
Total Phosphorus	g/m³P	0.019	0.027	0.024	0.270
Ammonia-N	g/m³N	0.007	<0.003	0.010	0.078
Nitrite	g/m³N	0.002	0.001	0.003	0.004
Nitrate	g/m³N	0.47	<0.01	0.03	0.96
TKN	g/m³N	0.13	0.19	0.22	0.54
Total nitrogen	g/m³N	0.60	0.20	0.25	1.50
pH		7.6	7.9	7.7	6.8

Table 15 Nutrient water quality monitoring data for Lake Rotorangi site L2: Hypolimnion (2014-2015)

Parameter		Date			
	Unit	22 Oct 2014	24 Feb 2015	23 Mar 2015	25 June 2015
Sample Depth	m	32	34	32	22
Dissolved Reactive Phosphorus	g/m^3P	0.018	0.011	0.005	0.004
Total Phosphorus	g/m^3P	0.028	0.022	0.019	0.458
Ammonia-N	g/m^3N	0.003	0.042	0.083	0.170
Nitrite	g/m^3N	<0.001	0.009	0.020	0.005
Nitrate	g/m^3N	0.79	0.64	0.48	0.73
TKN	g/m^3N	0.09	0.05	0.20	0.99
Total nitrogen	g/m^3N	0.88	0.70	0.70	1.72
pH		7.0	6.8	6.8	6.5

Table 16 Nutrient water quality monitoring data for Lake Rotorangi site L3: Epilimnion (2014-2015)

Parameter		Date			
	Unit	22 Oct 2014	24 Feb 2015	23 Mar 2015	25 June 2015
Sample Depth	m	3	3	3	4
Dissolved Reactive Phosphorus	g/m^3P	0.012	0.005	<0.003	0.012
Total Phosphorus	g/m^3P	0.033	0.023	0.010	0.33
Ammonia-N	g/m^3N	0.011	0.011	0.008	0.183
Nitrite	g/m^3N	0.002	0.001	0.002	0.012
Nitrate	g/m^3N	0.46	<0.01	0.02	0.59
TKN	g/m^3N	0.16	0.18	0.20	0.86
Total nitrogen	g/m^3N	0.62	0.19	0.22	1.46
pH		7.7	8.1	7.7	6.9

Table 17 Nutrient water quality monitoring data for Lake Rotorangi site L3: Hypolimnion (2014-2015)

Parameter	Unit	Date			
		22 Oct 2014	24 Feb 2015	23 Mar 2015	25 June 2015
Sample Depth	m	36	34	38	32
Dissolved Reactive Phosphorus	g/m^3P	0.019	0.008	0.004	0.008
Total Phosphorus	g/m^3P	0.020	0.024	0.008	0.672
Ammonia-N	g/m^3N	<0.003	<0.003	<0.003	0.336
Nitrite	g/m^3N	<0.001	0.001	0.002	0.008
Nitrate	g/m^3N	0.66	0.62	0.61	0.60
TKN	g/m^3N	0.07	0.02	0.03	1.63
Total nitrogen	g/m^3N	0.73	0.64	0.64	2.24
pH		6.8	6.6	6.8	6.5

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 (Tables 14 and 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, 2015). 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 at sites L2 and L3 where turbidities increased markedly after the mid-winter 2015 flood event.

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 (7.7 to 8.1), consistent with a small increase in mid and lower lake sites' phytoplankton photosynthetic activity (e.g. up to 111% dissolved oxygen saturation of the surface waters). More complete mixing of the lake waters, due to the influence of river flooding in particular, resulted in increases in certain nutrient concentrations and lower pH values (6.8 to 6.9) in mid winter 2015 at mid and lower lake sites.

3.1.5.3 Hypolimnion

Anoxic conditions in the hypolimnetic waters during stratification resulted in increases in ammonia-N levels (Tables 15 and 17) during the summer-autumn period at site L2, but not at site L3 where complete anoxia was not recorded over this period. pH levels were consistently close to neutral (6.5 to 7.0 units), often significantly lower (by up to 1.5 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 (in the epilimnion and hypolimnion) in winter when the lake was fully mixed following the recent severe flood event.

The lengthy period of partial to complete stratification at sites L2 and L3 contributed to the variability in nutrient concentrations. The total phosphorus levels at sites L2 and L3 showed some variability in relation to small changes in turbidity, particularly at site L3 in winter 2015, caused by elevated suspended sediment levels 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 July 2014

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	36	<0.003	0.040	0.008	38	<0.003	0.017	0.008
	Total phosphorus	g/m^{3}P	36	0.012	0.276	0.023	38	0.011	0.220	0.020
	Ammonia nitrogen	g/m^{3}N	36	0.015	0.622	0.154	38	0.014	0.289	0.122
	Nitrate + nitrite	g/m^{3}N	31	<0.01	0.70	0.37	38	0.02	0.70	0.43
	Temperature	°C	36	8.1	14.3	9.5	38	8.1	14.4	9.5
	Turbidity	NTU	36	2.4	310	9.9	38	1.6	230	4.5
	Dissolved oxygen	g/m^3	36	0	6.4	0	38	0	7.6	0
	pH		27	6.5	7.0	6.8	38	6.5	7.3	6.8
L3	Dissolved reactive phosphorus	g/m^{3}P	35	<0.003	0.032	0.007	38	<0.003	0.024	0.006
	Total phosphorus	g/m^{3}P	35	0.008	0.298	0.022	38	0.006	0.196	0.016
	Ammonia nitrogen	g/m^{3}N	35	<0.003	0.111	0.011	38	<0.003	0.064	0.007
	Nitrate + nitrite	g/m^{3}N	31	0.12	0.69	0.55	38	0.17	0.78	0.59
	Temperature	°C	35	7.4	14.7	9.2	38	7.7	14.9	9.4
	Turbidity	NTU	34	0.7	140	11	38	0.9	77	1.9
	Dissolved oxygen	g/m^{3}P	33	0	3.5	0.7	38	0	4.8	1.6
	pH		23	6.6	7.0	6.8	38	6.6	7.1	6.8

Historical median data (1996-2014) 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 2015 and March 2015 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 (Tables 15 and 17).

Table 19 Nutrient water quality monitoring data for Lake Rotorangi sites L2 and L3: lower hypolimnion (above the lake bed) in the 2014-2015 period

Site		L2		L3	
Parameter	Unit	25 Feb 2015	23 Mar 2015	24 Feb 2015	23 Mar 2015
Sample Depth	M	38	36	43	42
Dissolved Reactive Phosphorus	g/m^3P	0.012	0.005	0.011	0.006
Total Phosphorus	g/m^3P	0.031	0.014	0.017	0.012
Ammonia-N	g/m^3N	0.132	0.160	<0.003	<0.003
Nitrate + nitrite-N	g/m^3N	0.57	0.46	0.57	0.59
[Dissolved oxygen]	g/m^3	[0.1]	[0.1]	[0.3]	[0.3]
[Turbidity]	NTU	[3.8]	[5]	[2.5]	[1.6]
[pH]		[6.7]	[6.8]	[6.6]	[6.7]
[Total BOD_5]	g/m^3	[2.8]	[2.0]	[1.9]	[0.5]

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

During the summer stratification period anoxic conditions were present in the lower hypolimnion at both sites L2 and 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 L2 in February 2015 when there was a small increase in turbidity. Increases in ammonia nitrogen (0.090 and 0.077 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. Total phosphorus increased significantly on one occasion when turbidity indicated additional fine suspended sediment in the water column near the lakebed. Ammonia-N and nitrate-N were above 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. However, some ammonia-N release occurred at the mid-lake site under anoxic conditions in late summer-autumn 2015.

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 2014-2015 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 1990-2014 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-four 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.

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	nos/100 ml	9	53	5
E.coli	nos/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	nos/100 ml	4	<1	3
Ecoli	nos/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 2014-2015 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 2014, February 2015, March 2015, and June 2015. The phytoplankton samples were preserved with Lugol's iodine solution and all samples were later identified under a compound microscope using up to 400 x magnifications.

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 22 October 2014, 24 February, 23 March, and 25 June 2015. These samples were taken from within the photic zone (surface waters) of site L2 and L3. Tables 22 and 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 2014-2015 period

Date	20 October 14	24 February 2015	23 March 2015	25 June 2015
GREEN ALGAE				
Unidentified (unicellular)	P	P	P	
Closterium	P			
Ankistrodesmus	P	P	P	
Staurastrum			P	
Chlamydomonas			P	
Coelastrum			P	
Micractinium			P	
Pediastrum			P	
Eudorina		P	P	
Volvox sp		P		
CYANOBACTERIA				
Aphanocapsa		P	P	
DIATOMS				
Synedra			P	
Nitzschia			P	
Navicula	P			
Cyclotella	P			
Fragilaria		P	P	
GOLDEN BROWNS				
Mallomonas			P	
Dinobryon			P	
Synura		P		
EUGLENOIDS				
Trachelomonas	P		P	
CRYPTOPHYTES				
Crytomonas	A		P	
TOTAL	7	7	16	0

P – Present
A - Abundant

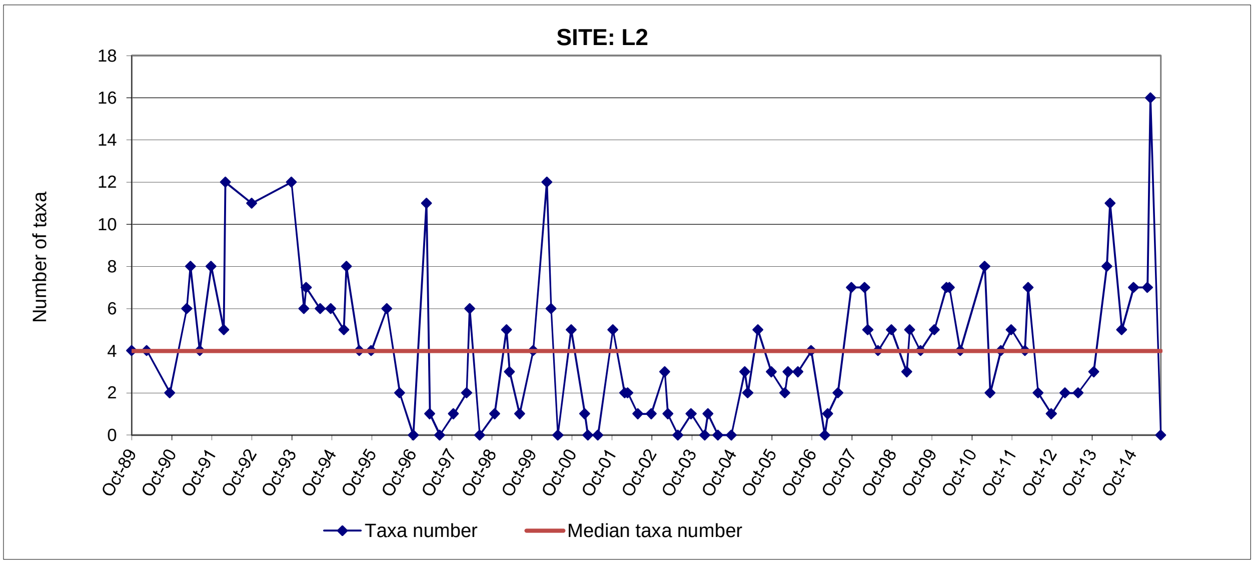


Figure 7 Number of phytoplankton taxa recorded at site L2 in lake Rotorangi since monitoring began in 1989

A wide range of numbers of taxa (0 to 16) was recorded at site L2 during the 2014-2015 monitoring period, with numbers above the historical median richness (4 taxa) on three occasion; reaching a maximum richness (16 taxa) after a lengthy dry late summer-autumn period. This was four taxa greater than previously recorded although none of these taxa was in abundance (Figure 7). No taxa were found following the extensive mid-winter flooding when the lowest chlorophyll-a concentration also was measured. Chlorophyll-a concentrations had a moderate range (<1 to 5.5 mg/m^3 (Table 11)), with the highest level (5.5 mg/m^3) coincident with maximum richness during late summer-autumn. Only one individual taxon was present on three survey occasions and one taxon was recorded as abundant (on one occasion in spring).

3.2.2.1.2 Site L3

A relatively wide range of numbers of taxa was found at L3 during the 2014-2015 monitoring period, mainly well above the historical median (3 taxa) richness, with the exception of the absence of taxa following the extensive mid-winter, 2015 flood event. This range was more variable than the trend of relatively low numbers and densities of taxa found during the past fourteen years. Ten to fourteen taxa were present on the late summer and autumn sampling occasions (Figure 8) coincident with chlorophyll-a concentrations of a relatively wide range (4.7 to 8.2 mg/m^3) whereas lower richnesses in winter and spring were coincident with chlorophyll-a concentrations from <1 to 1.6 mg/m^3). The maximum richness (14 taxa) found during the lengthy dry period was two taxa more than previously recorded at this site.

Table 23 Phytoplankton found at site L3 in Lake Rotorangi in the 2014-2015 period

Date	22 Oct 2013	19 Feb 2014	20 Mar 2014	4 Jul 2014
GREEN ALGAE				
Unidentified (unicellular)	P	P	P	
Closterium	P	P		
Ankistrodesmus			P	
Chlorella		P		
Oocystis		P		
Staurastrum		P	P	
Chlamydomonas		P		
Cosmarium		P		
Coelastrum		P	P	
Eudorina	P	P	A	
CYANOBACTERIA				
Aphanocapsa		A		
DIATOMS				
Synedra		P	P	
Nitzschia			P	
Navicula	P			
Fragilaria		P	P	
Melosira	P			
GOLDEN BROWNS				
Mallomonas		P		
DINOFLAGELLATES				
Peridinium			P	
CRYPTOPHYTES				
Cryptomonas	P	P	P	
TOTAL	6	14	10	0

P – Present
A - Abundant

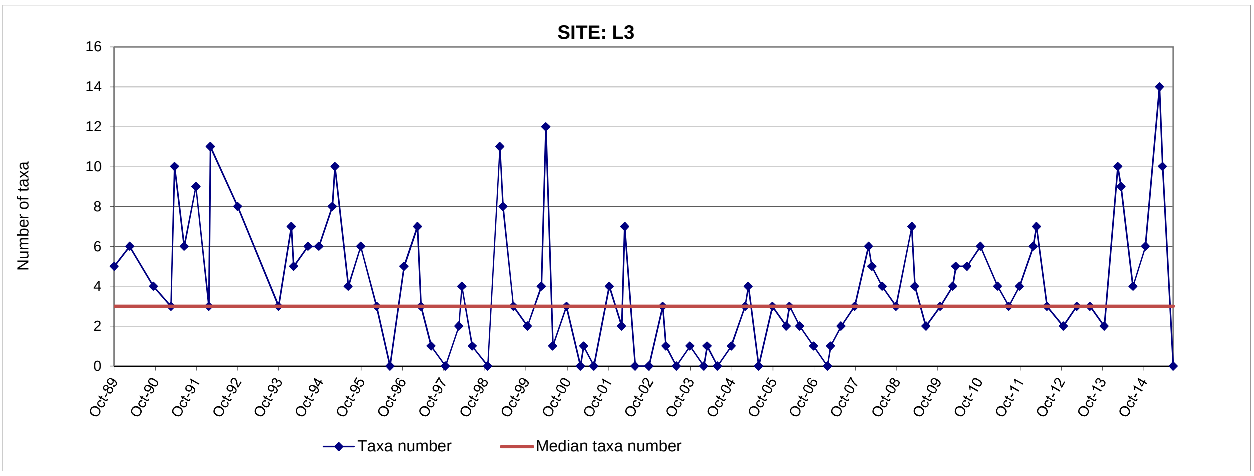


Figure 8 Number of taxa recorded at site L3 in Lake Rotorangi since monitoring began in 1989

Two individual taxa were present on three occasions and two taxa [green alga (*Eudorina*) and cyanobacterium (*Anabaena*)] were abundant on one occasion at the time of the late summer-autumn surveys.

3.2.2.1.4 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, a wider range of taxonomic richnesses was found at both sites throughout the 2014-2015 monitoring year with only three algal taxa, each on one occasion, found in abundance at either site. Taxa richnesses on all but one survey occasion were higher than the running median number of taxa recorded for each site to date. On one occasion (during a very dry summer-autumn period) at each site, these taxa numbers exceeded previous maximum richnesses by two to four taxa . 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 2014 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
Date	October 1992		June 1994		Sept 1994		October 1995		October 1996		October 1997		Nov 1998		October 1999		October 2000		October 2001		October 2002	
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 -
MOLLUSCA *Potamopyrgus* *Physa*	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	R R	- -	- -	- -	- -	- -	- -	- -	- -	- -	R -	R -
CRUSTACEA Copepoda Cladocera Ostracoda	R R C	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	R R R	- - -	R R R	- - -	- R C	- - -	- - -	- - -	- - C	- - - -
DIPTERA Orthocladiinae Tanypodinae *C.zealandicus*	- - R	- -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - -	- - - A	- - R	- - -	- - R	- - - --	- - - --
ACARINA		-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	R	-	-	-	-	-
Number of taxa	5	1	1	1	1	1	1	1	1	1	3	1	4	1	5	1	5	2	1	2	3	2

Site	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3
Date	October 2003		October 2004		October 2005		October 2006		October 2007		October 2008		October 2009		October 2010		October 2011		October 2012		October 2013	
ANNELIDA Oligochaeta *Branchiura*	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 -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
CRUSTACEA Copepoda Cladocera Ostracoda	R - C	- - - -	- - - -	- - - -	- - R	- - - -	- - - -	- - R	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - R	- - - R	- - C	- - - -
DIPTERA Orthocladiinae Tanypodinae *C.zealandicus*	- - C	- - -	- - R	- - R	- - R	- - --	- - --	- - --	- - --	- - -	- - --	- - --	- - --	- - --	- - --	- - --	- - R	- -- R	- - -	R R -	- - R	- -
ACARINA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Number of taxa	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 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 11). 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 10 and Photo 4).

Photo 4 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.

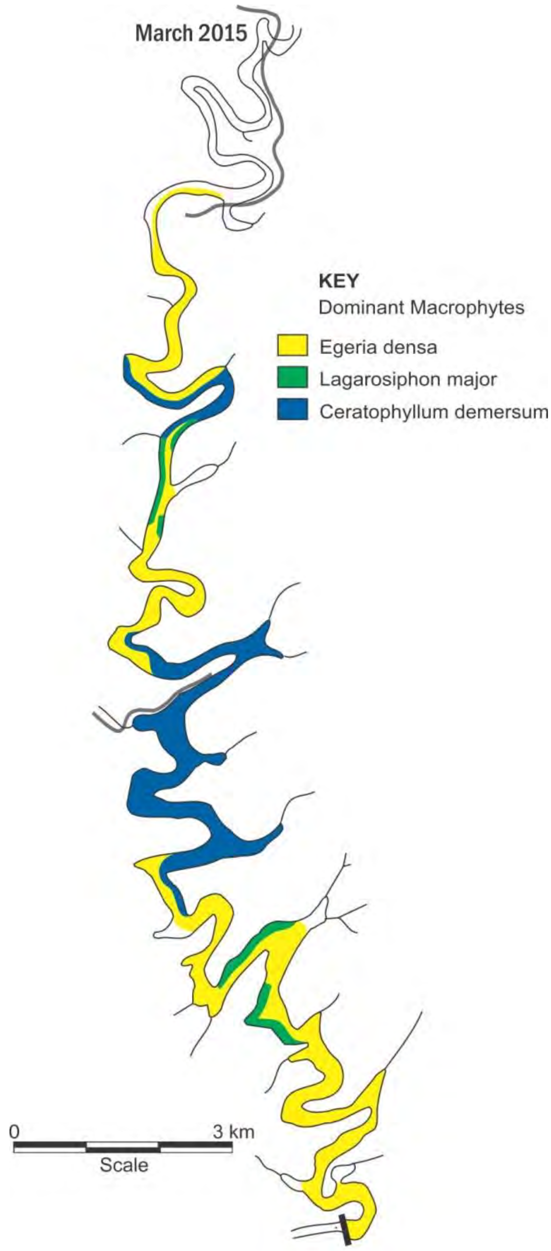

Figure 9 Dominant macrophytes in Lake Rotorangi, 2015

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.

[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.

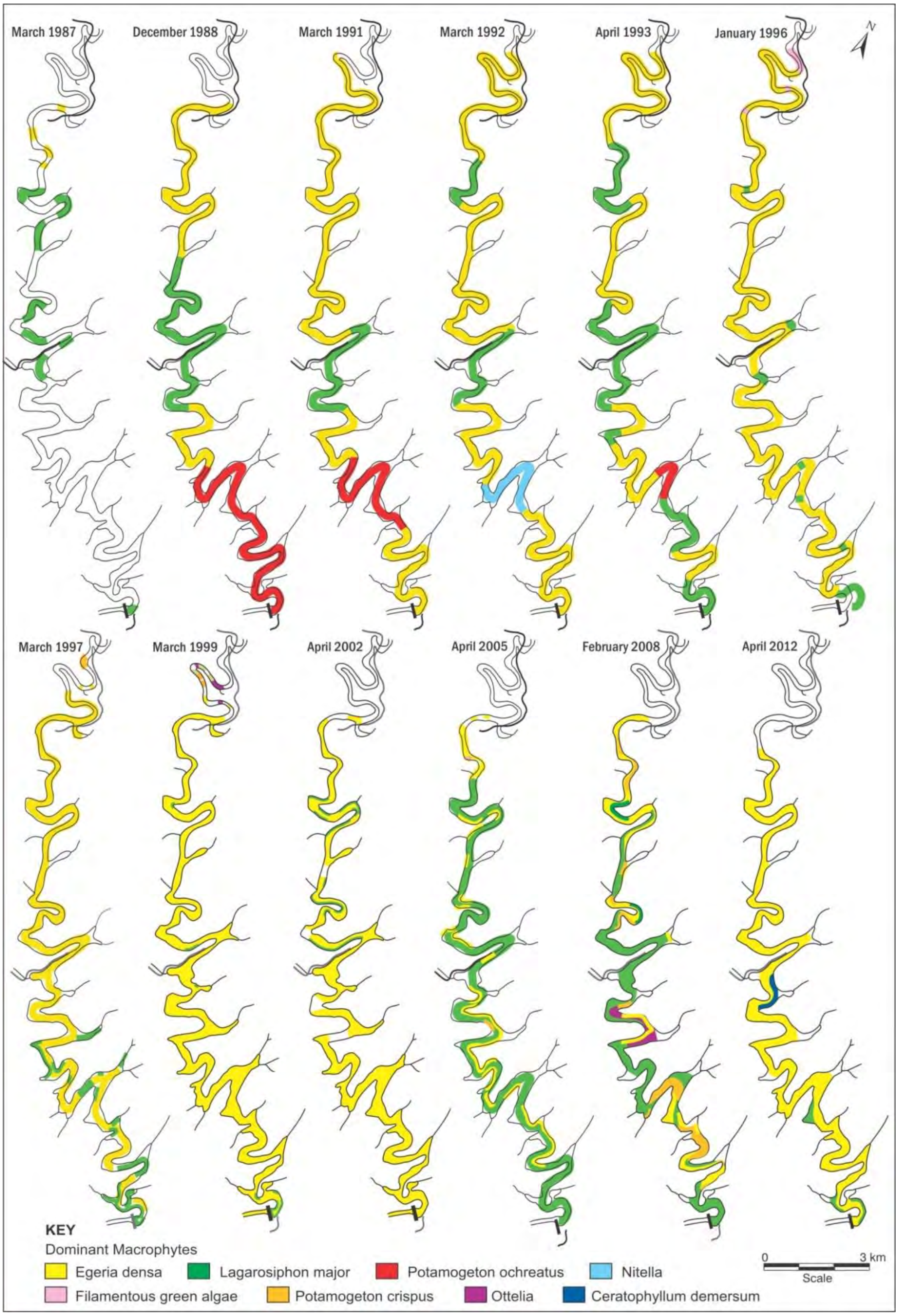

Figure 10 Dominant macrophytes in Lake Rotorangi from March 1987 to April 2012

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 of fish 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, it similar appearance to *P. ochreatus* may indicate that it would also be preferentially eaten by rudd (an omnivorous fish), and this may explain it's 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. Considering the proximity of Lake Rotokare to the Glen Nui boat ramp, it may be worthwhile controlling *C. demersum* in the vicinity of the Glen Nui boat ramp. This may be the subject of further investigation by the Taranaki Regional Council.

4. Conclusions

4.1 Discussion of 2014-2015 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 2015). Normal lake overturn was complete at site L2 and nearly complete at site L3 in mid-winter (June 2015) following very recent extensive flooding in the catchment. 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 carried out by the Council trend evaluation for the period 1990 to 2014 (Appendix II). However, relatively high turbidity levels (caused by riverine derived fine silt) from time to time have increased total phosphorus and nitrogen levels and lowered secchi disc values, indicative of a trend toward slightly eutrophic conditions (Burns, 2006). Nutrient supply has been limited principally to those quantities present in the river inflow waters. Despite low dissolved oxygen concentrations and periods of anoxic conditions in the lower waters of the hypolimnion, minimal increases in 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 (2014-2015) surveys were related to the recency of river freshes. Freshes prior to the and winter (2015) survey in particular increased turbidity, reducing secchi disc transparency at both sites to historically minimal levels in the lake. As has been noted in the past, lake surface water suspended solids concentrations generally were not excessive at mid and lower lake sites under dry weather conditions 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 24 year period 1990-2014 (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 levels. The analysis also notes that there are some insignificant increases in the average concentrations of key variables (secchi disc visibility, total phosphorus, and total nitrogen), with significant temporal increases in nitrate-nitrogen and chlorophyll-a.

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. Relatively wide ranges in the numbers of algal taxa were recorded partly as a result of the frequency of river freshes through the system and a lengthy very dry summer-autumn period. 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 autumn at both the mid lake site and at the lower lake site and very low under extremely turbid, flood flow conditions in mid-winter.

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. This may be the subject of further investigation by the Council. 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 2012-2013 period.

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 2013-2014 Report's recommendations

The recommendation contained in the 2013-2014 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 2014-2015).

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 2015-2016

In the case of the state of the environment monitoring programme for Lake Rotorangi, it is considered that the current monitoring is appropriate, with every third year of the programme to be performed in conjunction with the Patea Hydro Electric Power Scheme - aquatic monitoring plan, which is next to be conducted in the 2014-2015 period. No alterations are required to the 2015-2016 programme other than a reduction in frequency of the benthic macroinvertebrate component (to three-yearly), 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 2014-2015 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 Chris Fowles (Scientific Officer) who was the principal author of the Annual Report. Statistical trend analyses were provided by Fiza Hafiz (Scientific Officer) and the macrophyte survey was undertaken by Bart Jansma (Scientific Officer) and Ray Harris (Technical Officer). Field lake sampling surveys were performed by Chris Fowles and Bart Jansma assisted by boatpersons Robin Hughes, 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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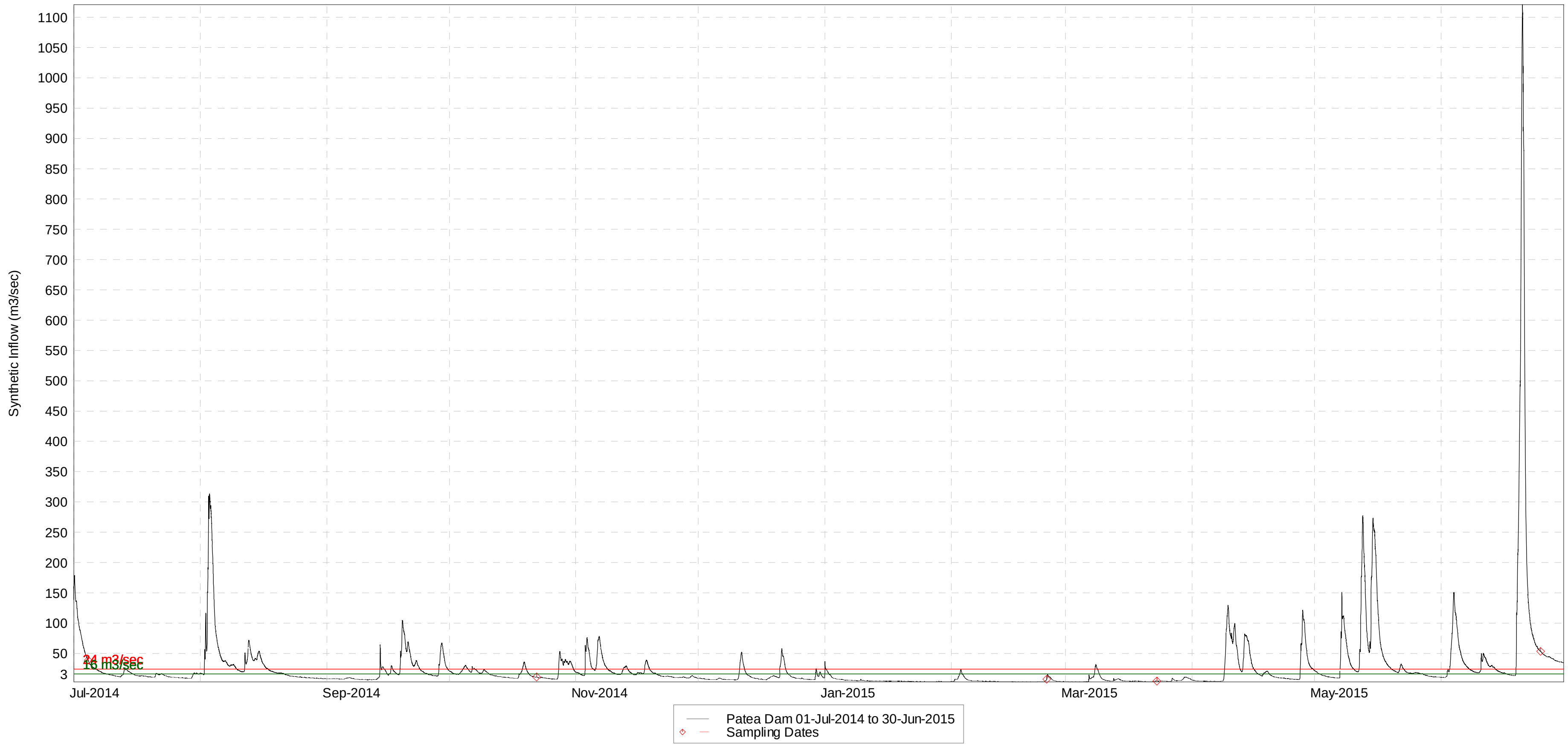
Appendix I

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 2014 to 30 June 2015

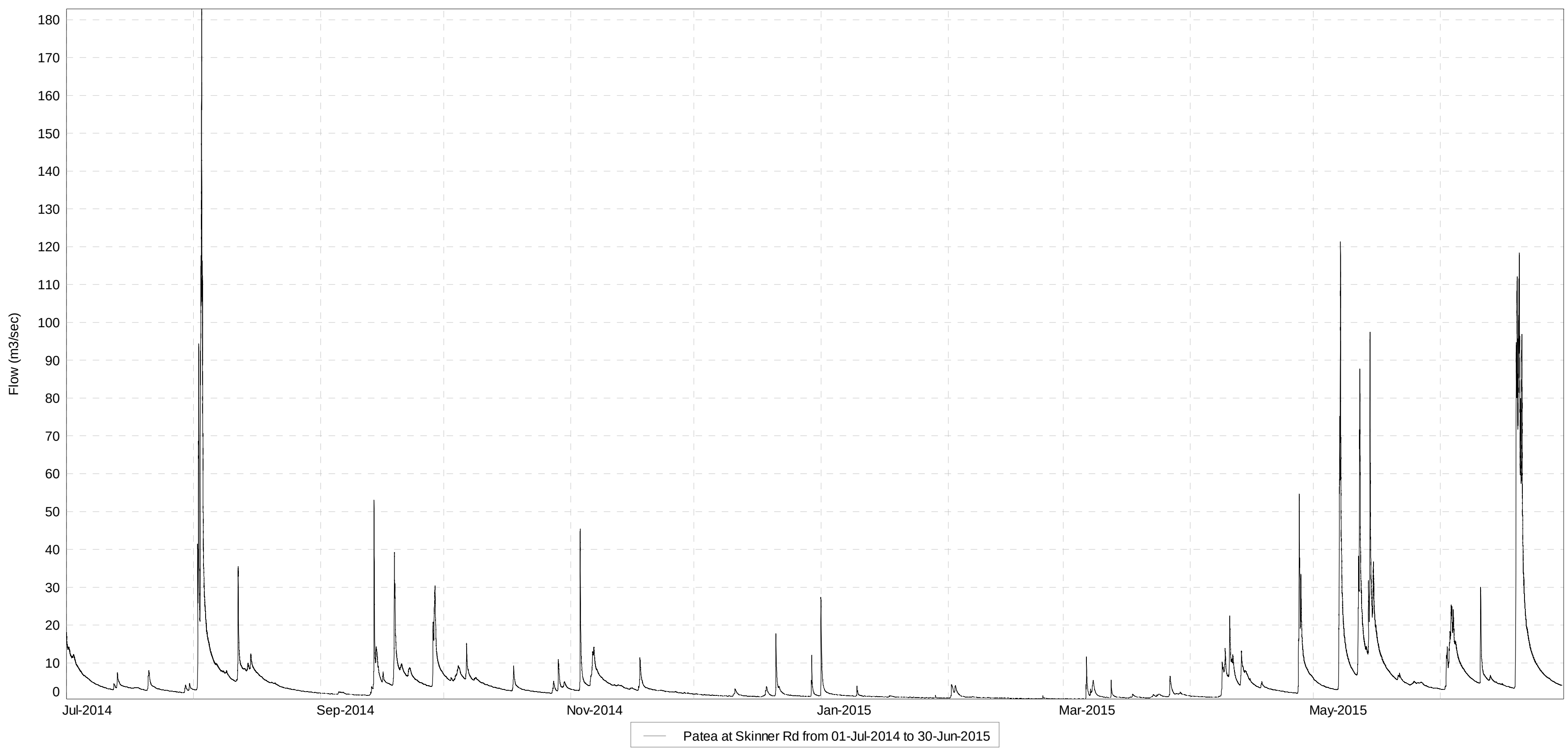


Synthetic Inflow (m3/sec)
1100
1050
1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
3
24 m3/sec
16 m3/sec
Jul-2014
Sep-2014
Nov-2014
Jan-2015
Mar-2015
May-2015
Patea Dam 01-Jul-2014 to 30-Jun-2015
Sampling Dates

Source is R:\PROCESSING-FILE\WATER TAKES & DISCHARGES.hts
Synthetic Inflow (m3/sec) at Patea Dam
From 1-Jul-2014 00:00:00 to 30-Jun-2015 24:00:00
24 hour periods beginning at midnight each day.

Daily means Years 2014-2015 Synthetic Inflow(m3/sec) at Patea Dam

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
1	141.837	16.330	8.064	19.084	17.970	8.772	22.592	4.702	3.313	5.394	19.373	10.351	
2	88.861	102.003	8.210	16.082	14.563	7.929	12.843	9.173	3.219	4.537	15.229	16.647	
3	57.685	277.438	8.111	17.144	50.282	7.051	8.506	17.834	3.142	4.195	12.831	64.194	
4	38.538	124.754	7.642	25.887	41.198	6.631	7.331	9.101	3.119	4.114	11.277	120.537	
5	28.412	57.595	8.433	24.789	24.212	7.234	6.572	5.533	3.206	4.069	10.303	62.394	
6	23.788	38.794	9.678	22.005	63.033	8.444	5.923	4.801	5.699	4.044	9.570	36.705	
7	19.879	33.995	8.280	22.920	45.901	7.047	5.559	4.684	10.218	3.938	68.894	27.230	
8	17.054	30.248	7.301	17.871	27.072	6.742	5.266	4.283	25.133	8.257	85.441	21.800	
9	15.276	28.038	6.816	20.944	20.618	6.550	5.400	3.968	13.019	92.618	40.881	18.904	
10	13.934	21.735	6.555	17.587	17.068	7.781	5.233	3.987	6.455	80.815	25.035	24.917	
11	12.453	23.447	6.572	14.146	15.389	39.227	4.809	3.889	4.942	79.832	21.389	43.568	
12	12.517	47.783	6.593	12.586	21.835	22.076	4.603	3.650	5.075	34.569	167.486	32.596	
13	21.873	49.203	9.555	11.481	26.080	12.845	4.506	3.494	7.171	42.316	143.685	28.550	
14	20.047	40.496	29.403	10.686	18.110	9.710	4.438	3.468	6.244	73.889	78.496	23.355	
15	15.997	47.816	19.624	10.012	15.286	8.285	4.314	3.388	4.612	38.879	240.994	19.289	
16	13.430	32.031	20.229	9.253	18.007	7.234	4.186	3.258	4.177	20.839	132.817	17.463	
17	12.968	24.358	20.632	9.197	19.509	6.854	4.212	3.164	4.175	14.815	55.060	15.217	
18	12.401	20.538	17.238	18.520	33.444	10.019	4.313	3.116	4.376	16.137	35.449	13.704	
19	11.329	18.186	77.329	29.673	20.658	12.557	4.183	3.085	3.979	19.067	26.648	105.237	
20	10.992	17.511	63.649	16.549	16.656	10.987	4.026	3.095	3.688	13.235	21.473	669.172	
21	15.799	16.186	46.397	11.944	13.672	43.700	3.882	3.145	3.515	10.823	20.593	584.741	
22	15.717	13.747	32.510	10.526	12.212	24.482	3.768	3.464	3.826	9.746	27.908	131.525	
23	13.084	12.425	28.254	10.017	12.295	13.412	3.651	3.635	4.372	9.077	19.698	79.631	
24	11.234	11.652	19.956	9.363	11.224	10.116	3.558	9.774	4.545	8.228	17.442	61.081	
25	10.546	10.908	16.394	8.519	10.228	8.748	3.500	8.546	4.245	7.561	17.788	52.490	
26	10.087	10.313	14.401	7.736	10.266	8.403	3.467	4.658	4.116	7.081	17.393	46.565	
27	9.694	9.860	13.157	16.107	10.654	7.421	3.491	3.778	6.735	35.161	15.828	43.937	
28	9.228	9.379	31.451	40.669	9.645	6.816	3.564	3.498	5.107	93.735	13.487	40.439	
29	9.156	8.969	52.842	36.841	12.197	11.125	3.655		6.515	38.616	12.034	37.208	
30	16.003	8.601	25.649	34.523	9.961	15.694	3.508		10.523	24.859	11.312	35.564	
31	16.645	8.265		23.961		11.725	3.519		7.970		10.870		
Min	9.156	8.265	6.555	7.736	9.645	6.550	3.467	3.085	3.119	3.938	9.570	10.351	3.085
Mean	23.434	37.826	21.031	17.956	21.308	12.117	5.432	5.078	6.014	27.015	45.377	82.850	25.481
Max	141.837	277.438	77.329	40.669	63.033	43.700	22.592	17.834	25.133	93.735	240.994	669.172	669.172

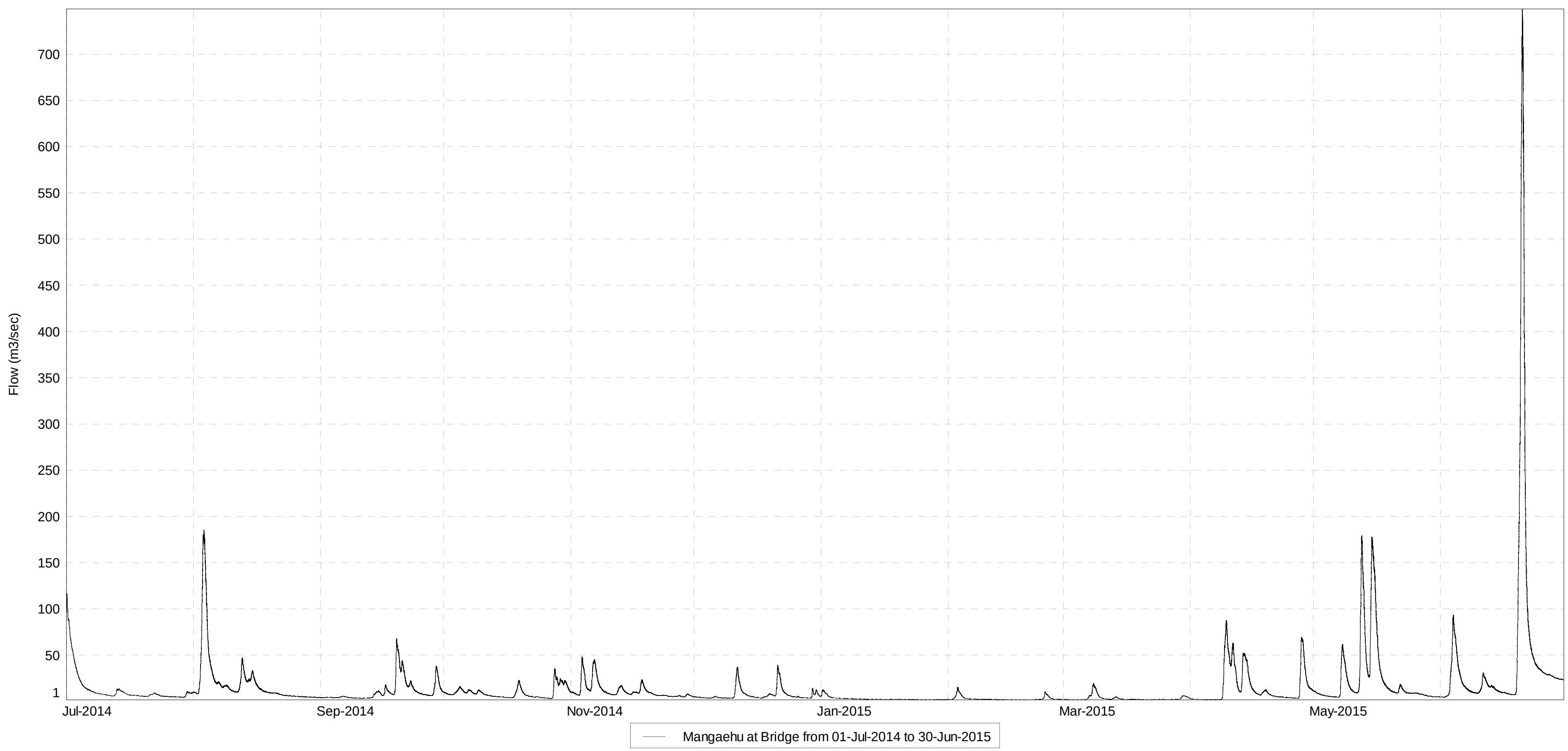


Flow (m3/sec)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Jul-2014
Sep-2014
Nov-2014
Jan-2015
Mar-2015
May-2015
Patea at Skinner Rd from 01-Jul-2014 to 30-Jun-2015

Source is R:\ARCHIVES\HYDRO-ARCHIVES.HTS
Flow (m3/sec) at Patea at Skinner Rd
From 1-Jul-2014 00:00:00 to 30-Jun-2015 24:00:00
24 hour periods beginning at midnight each day.

Daily means Years 2014-2015 Flow(m3/sec) at Patea at Skinner Rd

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
1	14.068	4.600	1.958	6.358	2.912	1.756	6.456	1.594	0.475	1.209	5.318	3.001	
2	11.722	68.646	1.868	5.616	2.711	1.646	2.188	3.002	0.478	1.112	4.472	8.128	
3	9.621	51.303	1.802	5.743	12.328	1.551	1.793	1.889	0.459	1.057	3.891	18.489	
4	7.752	16.745	1.728	8.099	4.729	1.473	1.621	1.166	0.466	1.016	3.479	16.685	
5	6.511	11.876	2.123	6.613	4.702	1.437	1.500	0.972	0.471	0.967	3.186	11.022	
6	5.658	9.643	2.104	8.176	11.126	1.380	1.405	0.967	2.776	0.924	2.954	8.602	
7	4.815	8.226	1.773	6.451	7.795	1.304	1.326	0.962	2.009	0.937	44.544	7.070	
8	4.249	7.551	1.647	5.739	6.113	1.260	1.239	0.840	3.528	3.630	19.288	5.952	
9	3.780	6.823	1.551	5.318	5.164	1.227	1.660	0.815	1.440	8.903	11.220	5.162	
10	3.402	5.599	1.495	4.648	4.470	1.544	1.467	0.828	1.056	10.546	8.359	9.481	
11	3.105	9.606	1.492	4.194	4.104	2.187	1.212	0.786	0.875	9.493	9.269	7.822	
12	3.473	10.388	1.450	3.826	4.054	1.453	1.168	0.735	1.552	5.127	39.541	5.732	
13	4.937	8.284	4.312	3.492	3.810	1.262	1.121	0.697	1.264	8.132	15.823	5.809	
14	4.057	9.328	15.108	3.245	3.287	1.186	1.078	0.690	0.923	7.531	28.882	4.875	
15	3.671	9.200	6.431	2.992	3.216	1.134	1.056	0.669	0.835	5.601	28.037	4.422	
16	3.403	7.384	5.640	2.770	3.027	1.068	1.012	0.632	0.786	4.363	17.341	4.117	
17	3.369	6.346	4.564	3.138	4.656	1.101	1.090	0.596	1.027	3.660	12.031	3.701	
18	3.358	5.467	7.871	5.129	5.041	2.334	1.125	0.589	1.235	4.077	9.403	3.424	
19	3.005	4.858	15.188	3.359	3.402	1.711	0.980	0.560	0.929	3.482	7.729	56.038	
20	3.222	4.665	8.871	2.916	3.051	2.360	0.944	0.569	0.817	3.093	6.427	82.274	
21	5.319	4.146	7.327	2.708	2.828	5.321	0.912	0.570	0.767	2.845	6.013	28.853	
22	3.581	3.637	7.715	2.541	2.700	2.235	0.872	0.559	1.027	2.675	5.885	16.441	
23	3.104	3.341	6.482	2.386	2.626	1.639	0.864	0.551	1.332	2.486	4.767	11.983	
24	2.859	3.112	5.359	2.255	2.437	1.436	0.838	0.738	1.567	2.323	4.313	9.568	
25	2.702	2.901	4.709	2.155	2.338	1.330	0.808	0.562	1.181	2.169	4.783	7.920	
26	2.531	2.715	4.230	2.055	2.303	1.262	0.795	0.525	1.188	2.059	4.684	6.692	
27	2.399	2.550	3.863	2.990	2.082	1.191	0.796	0.512	3.680	18.648	4.644	5.858	
28	2.241	2.401	16.362	3.602	2.038	1.133	0.829	0.498	1.828	14.739	3.919	5.093	
29	2.364	2.259	11.896	4.918	1.974	2.983	0.775		1.893	8.358	3.559	4.499	
30	3.240	2.167	7.828	4.209	1.806	1.847	0.719		1.602	6.646	3.357	4.070	
31	3.381	2.055		3.283		2.807	0.695		1.353		3.203		
Min	2.241	2.055	1.450	2.055	1.806	1.068	0.695	0.498	0.459	0.924	2.954	3.001	0.459
Mean	4.545	9.607	5.492	4.223	4.094	1.728	1.301	0.860	1.317	4.927	10.655	12.426	5.118
Max	14.068	68.646	16.362	8.176	12.328	5.321	6.456	3.002	3.680	18.648	44.544	82.274	82.274


Flow (m3/sec)
700
650
600
550
500
450
400
350
300
250
200
150
100
50
1
Jul-2014
Sep-2014
Nov-2014
Jan-2015
Mar-2015
May-2015
Mangaehu at Bridge from 01-Jul-2014 to 30-Jun-2015

Source is R:\ARCHIVES\HYDRO-ARCHIVES.HTS
Flow (m3/sec) at Mangaehu at Bridge
From 1-Jul-2014 00:00:00 to 30-Jun-2015 24:00:00
24 hour periods beginning at midnight each day.

Daily means Years 2014-2015 Flow(m3/sec) at Mangaehu at Bridge

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
1	90.880	9.096	4.050	8.833	9.387	4.649	10.055	2.116	1.783	2.479	10.069	4.523	
2	55.017	27.329	4.222	7.323	7.259	4.179	7.051	4.194	1.710	2.019	7.769	5.599	
3	34.073	153.621	4.189	8.065	26.181	3.705	4.218	11.104	1.661	1.833	6.442	33.236	
4	21.388	76.207	3.904	12.692	24.176	3.496	3.521	5.273	1.653	1.795	5.560	72.906	
5	15.045	32.778	4.248	12.679	12.540	3.917	3.226	2.927	1.690	1.790	5.016	35.418	
6	12.329	20.724	5.132	9.752	36.159	4.716	2.971	2.478	1.966	1.788	4.623	18.860	
7	10.166	18.303	4.319	11.405	25.480	3.747	2.784	2.395	5.666	1.715	18.232	13.401	
8	8.649	16.217	3.717	8.414	13.462	3.560	2.647	2.200	15.370	3.260	47.117	10.425	
9	7.784	14.960	3.459	10.842	9.710	3.452	2.510	2.006	7.809	60.203	21.036	9.072	
10	7.123	11.279	3.327	8.828	7.877	4.304	2.462	2.013	3.444	49.371	11.715	10.759	
11	6.268	10.242	3.343	6.746	7.087	26.996	2.367	1.961	2.585	49.475	9.508	25.106	
12	6.078	26.923	3.388	5.825	11.734	14.311	2.263	1.818	2.287	19.614	92.464	18.664	
13	11.733	29.404	4.470	5.222	14.721	7.952	2.224	1.725	3.819	24.207	89.985	15.928	
14	10.872	22.581	9.138	4.789	9.512	5.732	2.204	1.710	3.345	46.450	37.501	12.789	
15	8.341	27.827	9.010	4.461	7.797	4.697	2.135	1.662	2.359	22.941	151.078	10.274	
16	6.767	17.450	10.447	4.059	9.753	3.963	2.075	1.584	2.105	11.498	81.369	9.291	
17	6.472	12.643	11.180	3.911	10.059	3.696	2.057	1.555	1.993	7.788	30.526	8.086	
18	6.009	10.512	7.837	8.959	19.258	5.181	2.080	1.538	1.944	8.579	18.183	7.294	
19	5.485	9.297	44.460	17.989	11.410	7.422	2.085	1.540	1.871	10.962	13.043	38.973	
20	5.243	8.989	39.796	8.887	8.968	6.446	2.001	1.545	1.727	7.125	10.245	424.632	
21	6.874	8.387	27.974	5.891	7.142	27.366	1.916	1.581	1.635	5.525	10.085	386.658	
22	8.241	7.038	17.828	4.952	6.257	15.302	1.854	1.837	1.724	4.859	15.226	82.832	
23	6.719	6.298	15.269	4.683	6.405	7.982	1.772	1.974	1.860	4.500	10.049	49.669	
24	5.538	5.874	10.158	4.272	5.764	5.779	1.720	6.294	1.828	4.015	8.831	38.319	
25	5.149	5.473	8.145	3.736	5.128	4.818	1.692	5.350	1.851	3.662	8.748	33.440	
26	4.942	5.163	7.092	3.272	5.225	4.602	1.674	2.656	1.801	3.434	8.464	29.956	
27	4.758	4.944	6.455	9.042	5.706	3.936	1.690	2.090	1.868	13.591	7.390	28.653	
28	4.541	4.697	11.520	25.427	5.022	3.560	1.733	1.902	1.998	56.718	6.213	26.565	
29	4.487	4.496	28.892	21.257	7.026	5.533	1.810		2.879	21.774	5.394	24.585	
30	8.791	4.292	12.378	20.182	5.466	9.331	1.742		5.733	13.109	5.002	23.704	
31	9.015	4.127		13.235		6.766	1.770		4.037		4.762		
Min	4.487	4.127	3.327	3.272	5.022	3.452	1.674	1.538	1.635	1.715	4.623	4.523	1.538
Mean	13.057	19.909	10.978	9.214	11.389	7.132	2.655	2.751	3.032	15.536	24.569	50.321	14.220
Max	90.880	153.621	44.460	25.427	36.159	27.366	10.055	11.104	15.370	60.203	151.078	424.632	424.632

Appendix II

TRC Lake Rotorangi water quality trend analysis 1990-2014

Memorandum

To CR Fowles, Scientific Officer
From Fiza Hafiz, Scientific Officer SEM
Document #1595124
Date 6 November 2015

Lake Rotorangi trend analysis January 1990 to December 2014

Introduction

A trend analysis of Lake Rotorangi monitoring data from 1990 to 2014 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 provides the *p* and R values for these trends.

This trend analysis indicates that while many of the parameters are not significantly changing over time, there is significant deterioration in nitrate nitrogen and chlorophyll a when both sites are considered together. The Percent Annual Change (PAC) was calculated for those trends which were significant (PAC=slope/period average*100) and indicated that when data from sites L2 and L3 are combined, nitrate nitrogen is increasing by 2.0% per year (or 6.37 $mgN/m^3/year$) and chlorophyll *a* is increasing by 2.2% per year (0.07 $mg/m^3/year$).

The trend for total suspended solids however is showing improvement (i.e. a decline of 4.2% per year (0.16 $mg/m^3/year$)). Figure 1, Figure 2 and Figure 3 present the significant trends graphically for the combined sites data. Trends are presented graphically for all parameters for combined sites (Appendix 2) and individual sites (Appendices 3 and 4).

Table 1 Trends in water quality parameters in Lake Rotorangi for monitoring conducted from 1990 to 2014

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

Key:

- 🙂 (dark green) statistically very significant **improvement** P<0.01 (1%)
- 🙂 (light green) statistically significant **improvement** P<0.05 (1%)
- 😐 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)

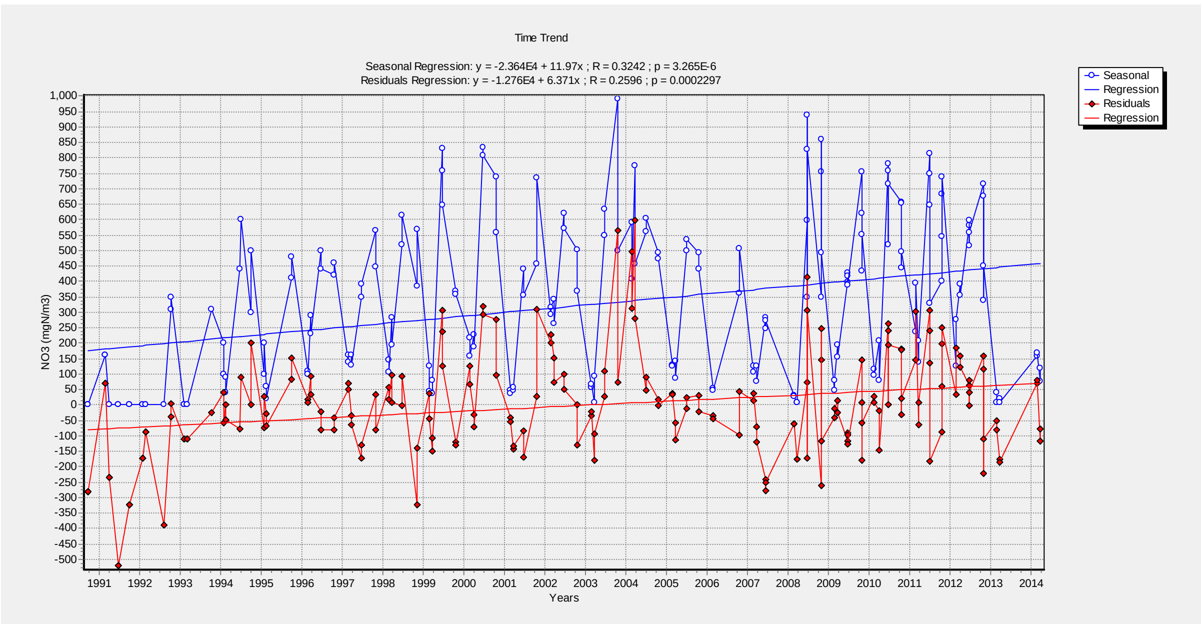


Figure 1: Nitrate nitrogen (NO3) trend line for sites L2 and L3 combined

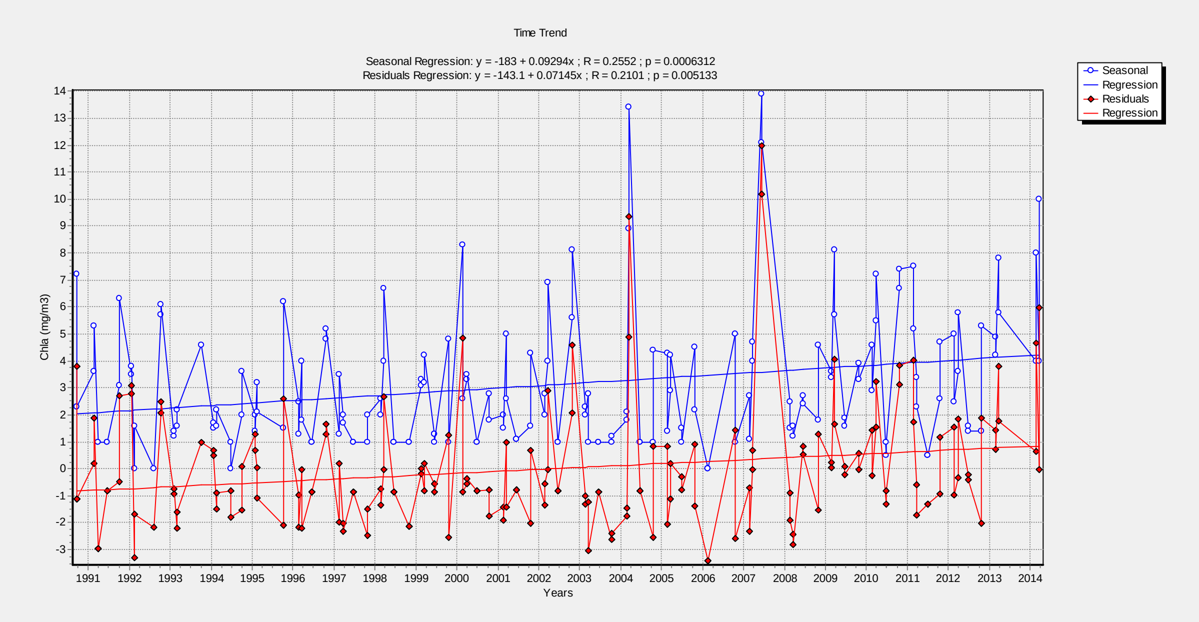


Figure 2: Chlorophyll a trend line for sites L2 and L3 combined

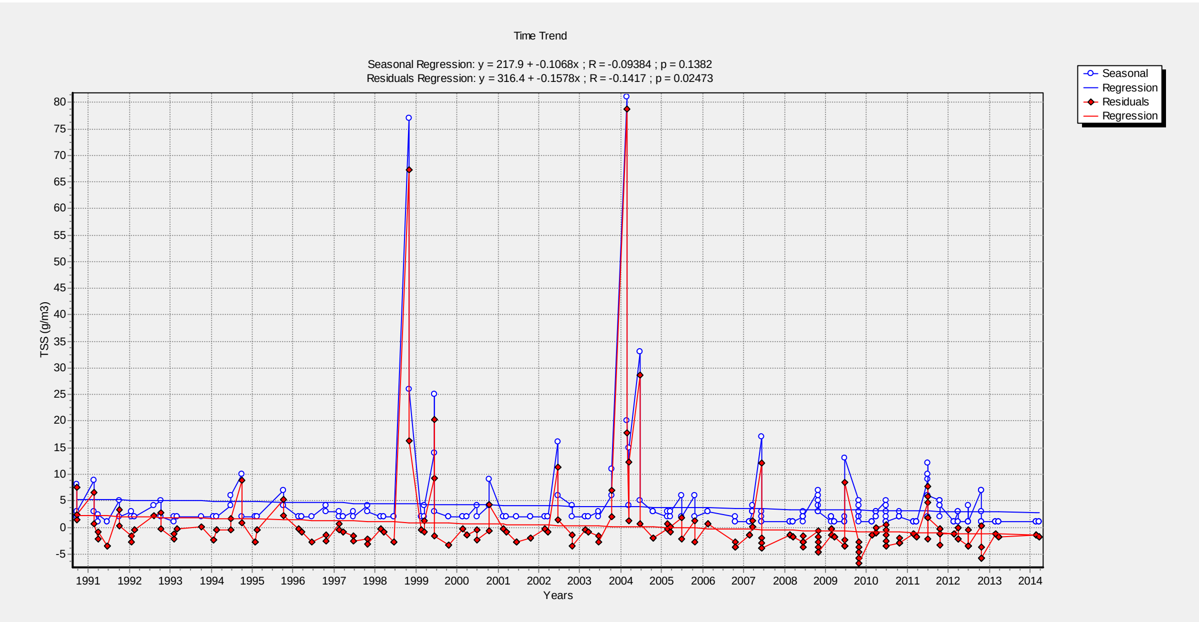


Figure 3: Total suspended solids trend line for sites L2 and L3 combined

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 1990-2014 period is 4.16 (±0.06) (Table 2). This indicates that the lake is eutrophic as per the following table (reproduced from Burns (2006)). However, when the individual key variables are compared with the trophic levels, chlorophyll a 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 has dropped into the mesotrophic boundary within this year's analysis. Therefore site L2 continues to be more eutrophic at a TLI of 4.24 (possibly as a result of this site's proximity to the upper catchment) due to the 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 (3.87) indicated mesotrophic conditions in the 2014 year of monitoring.

The TLI is not changing significantly over time (i.e., the trend is not significant at $p<0.05$). However in Burns' (2006) report, he notes that while there are no 'significant' trends in the trophic level or the average concentrations of the key variables (Chl a, Secchi, TP, TN), there are some insignificant increases in these variables; and coupled with significant trend in NO_3, suggests that the trophic level is increasing, albeit at a very small rate of change (0.01 ±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 1990-2014 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'. 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 1990-2014 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, however on the basis of work currently being undertaken by NIWA and MfE, it may not be applicable for future 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 this data should be viewed with caution. TRC will continue to be updated with national monitoring protocols and follow any guidance and instruction where necessary when monitoring and reporting on Lake Rotorangi.

Table 3 *p* and R values for trend analysis of 1990-2014 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	0.036	0.23	0.06	0.19	0.005	0.21
DO	0.28	-0.11	0.93	0.01	0.59	-0.04
EC	0.055	0.17	0.69	0.04	0.11	0.10
Secchi Depth	0.34	0.10	0.46	-0.08	0.97	0.003
TSS	0.09	-0.15	0.03	-0.20	0.02	-0.14
Temperature	0.56	-0.06	0.79	0.03	0.82	-0.02
DRP	0.37	0.09	0.86	-0.02	0.59	0.04
NH_4	0.93	0.01	0.80	-0.03	0.99	0.0003
NO_3	0.016	0.24	0.004	0.287	0.0002	0.26
TN	0.85	0.02	0.81	-0.02	0.98	-0.002
TP	0.99	-0.002	0.84	0.02	0.94	0.005
HVOD	0.19	0.28	0.15	-0.31	0.64	-0.10
TLI	0.55	0.06	0.07	0.21	0.19	0.13

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

References

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

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

Connolly A, 2012: Lake Rotorangi trend analysis January 1990 to December 2011. TRC Internal Memo.

Hafiz F., 2013: Lake Rotorangi trend analysis January 1990 to December 2012. TRC Internal Memo.

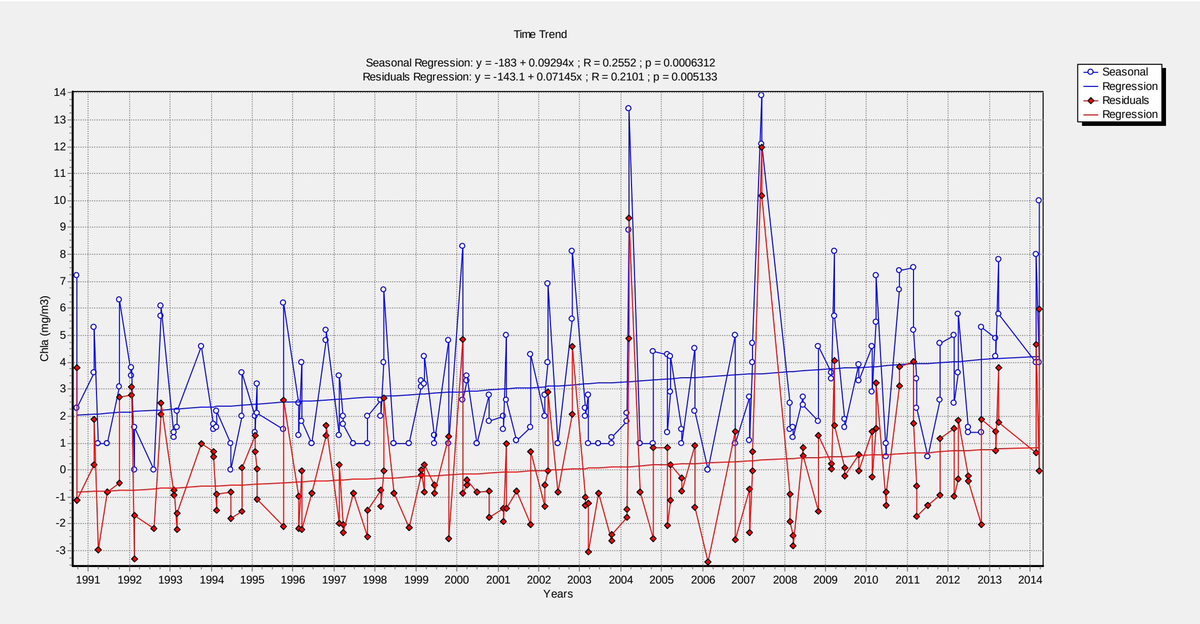
Hafiz F., 2014: Lake Rotorangi trend analysis January 1990 to December 2013. TRC Internal Memo

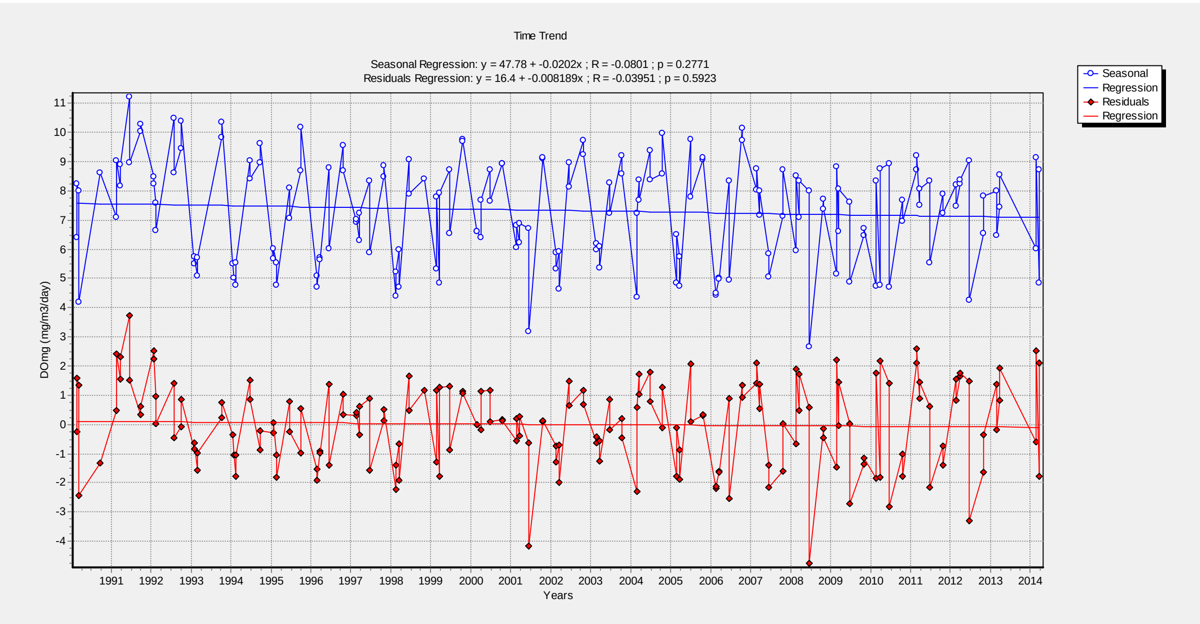
NIWA, 2011: Investigation of single indicators for water quality assessment and reporting- Prepared for the Ministry for the Environment. 108-113p.

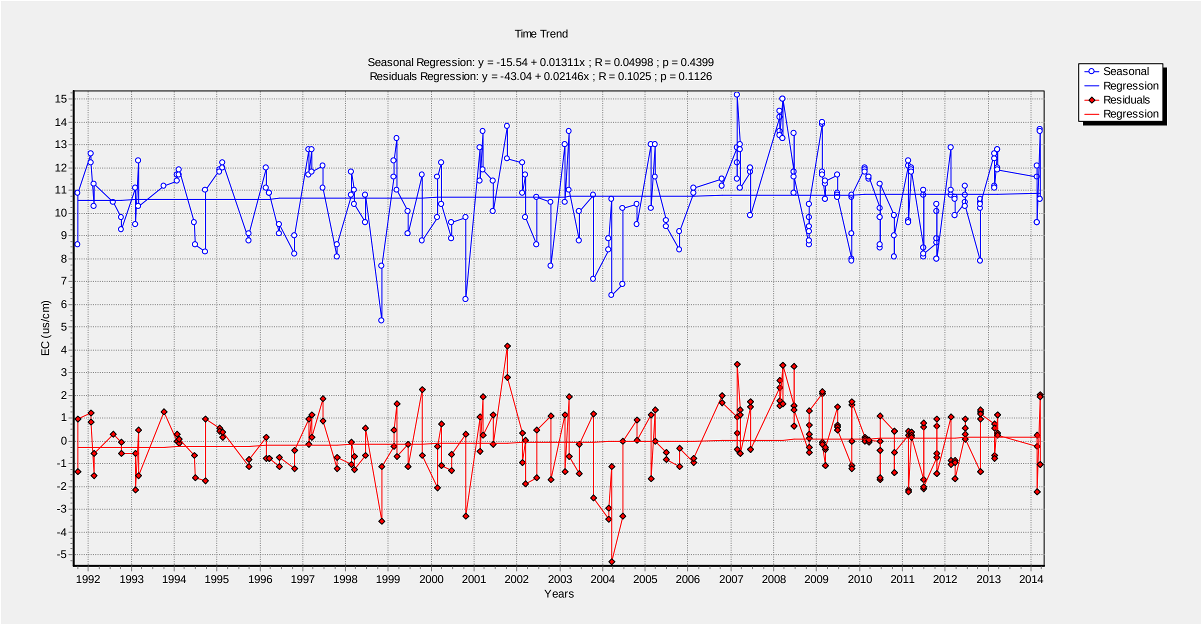
Appendix 2

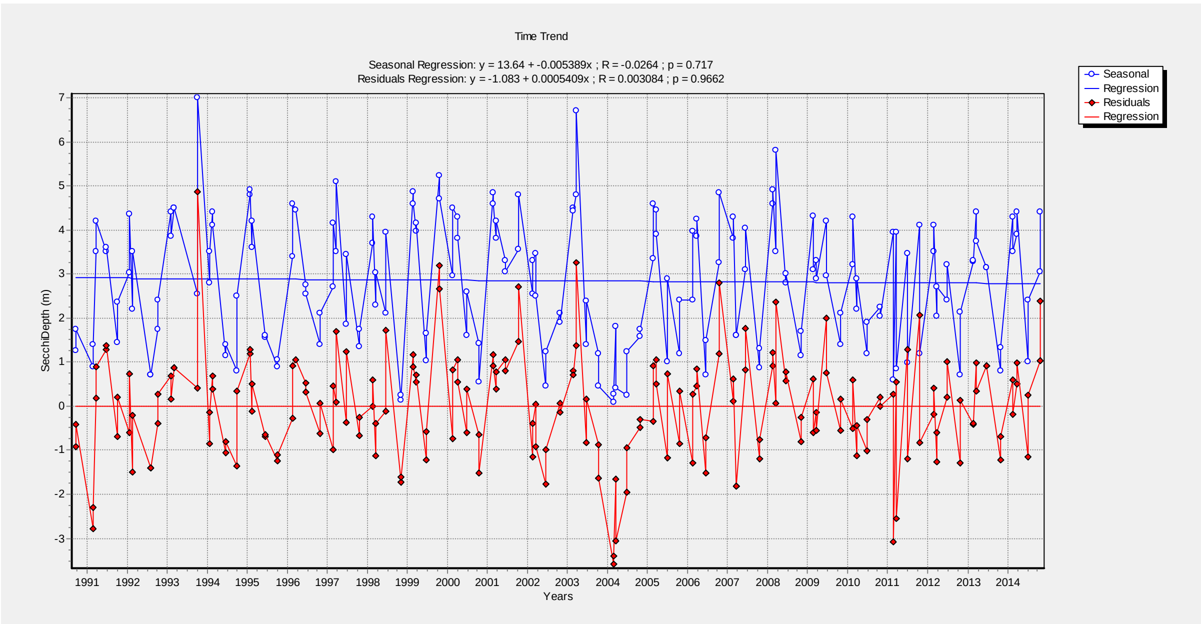
Physical parameters – Site L2 and L3 combined

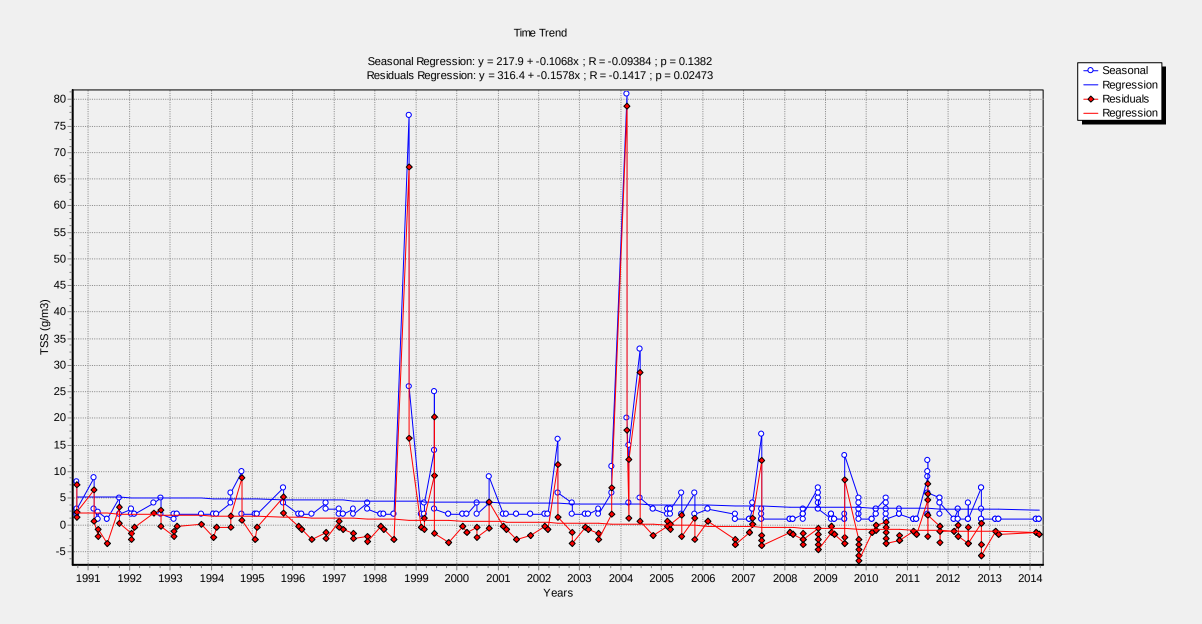
L2 and L3 combined – Physical parameters



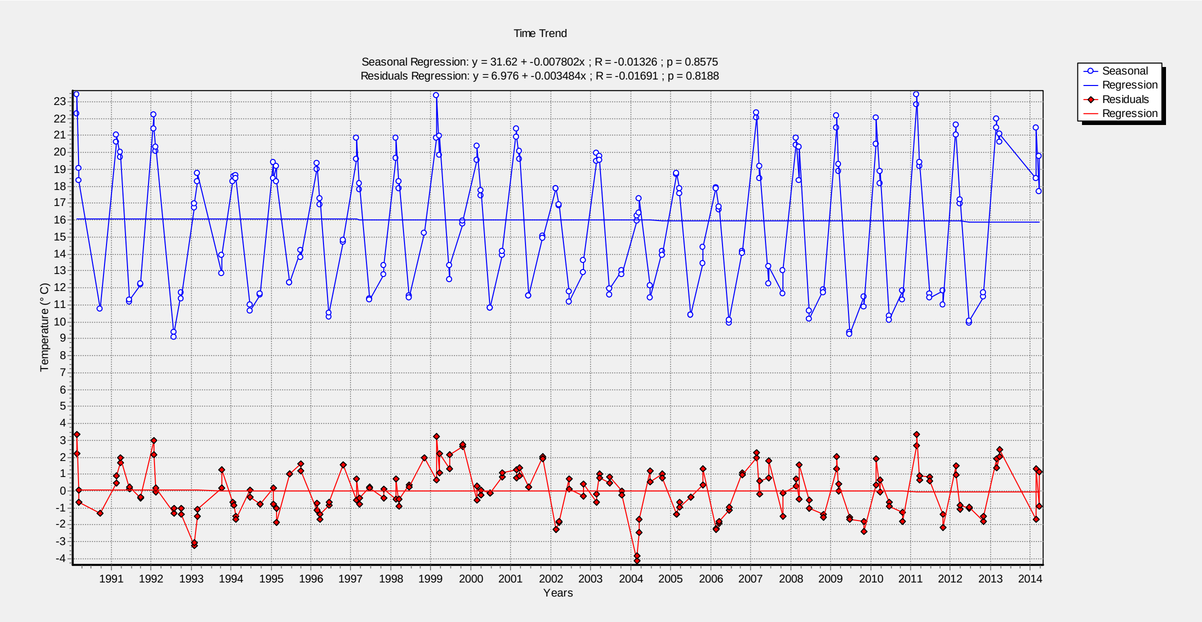



Time Trend
Seasonal Regression: y = -15.54 + 0.01311x ; R = 0.04998 ; p = 0.4399
Residuals Regression: y = -43.04 + 0.02146x ; R = 0.1025 ; p = 0.1126
EC (us/cm)
Years
Seasonal
Regression
Residuals
Regression


Time Trend
Seasonal Regression: y = 13.64 + -0.005389x ; R = -0.0264 ; p = 0.717
Residuals Regression: y = -1.083 + 0.0005409x ; R = 0.003084 ; p = 0.9662
SecchiDepth (m)
Years
Seasonal
Regression
Residuals
Regression

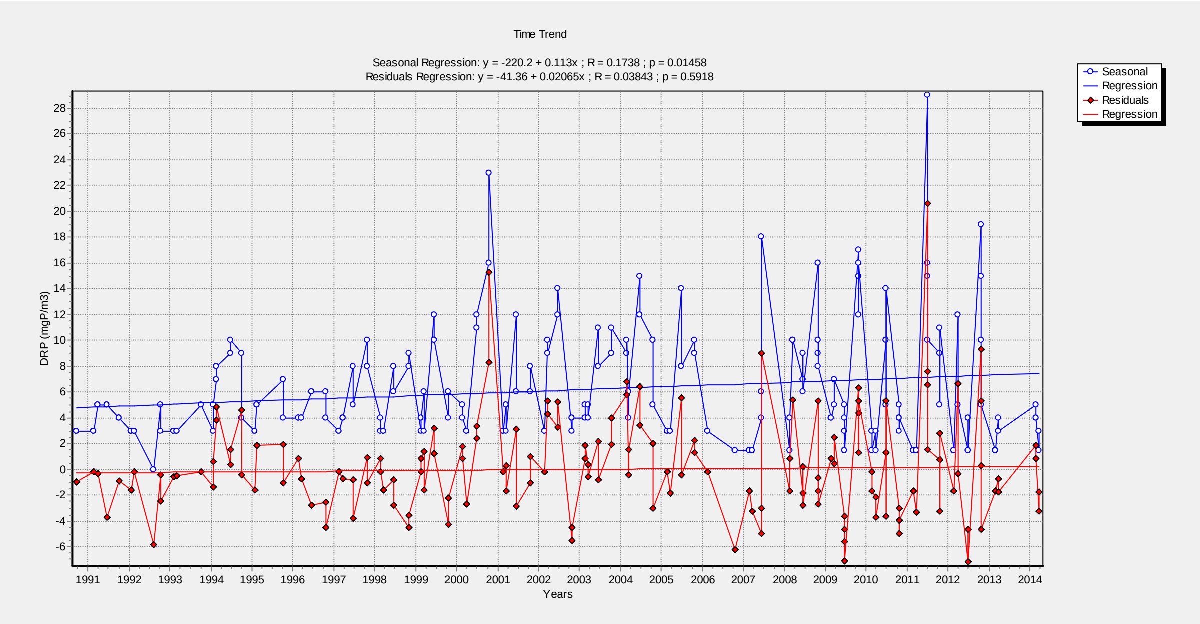


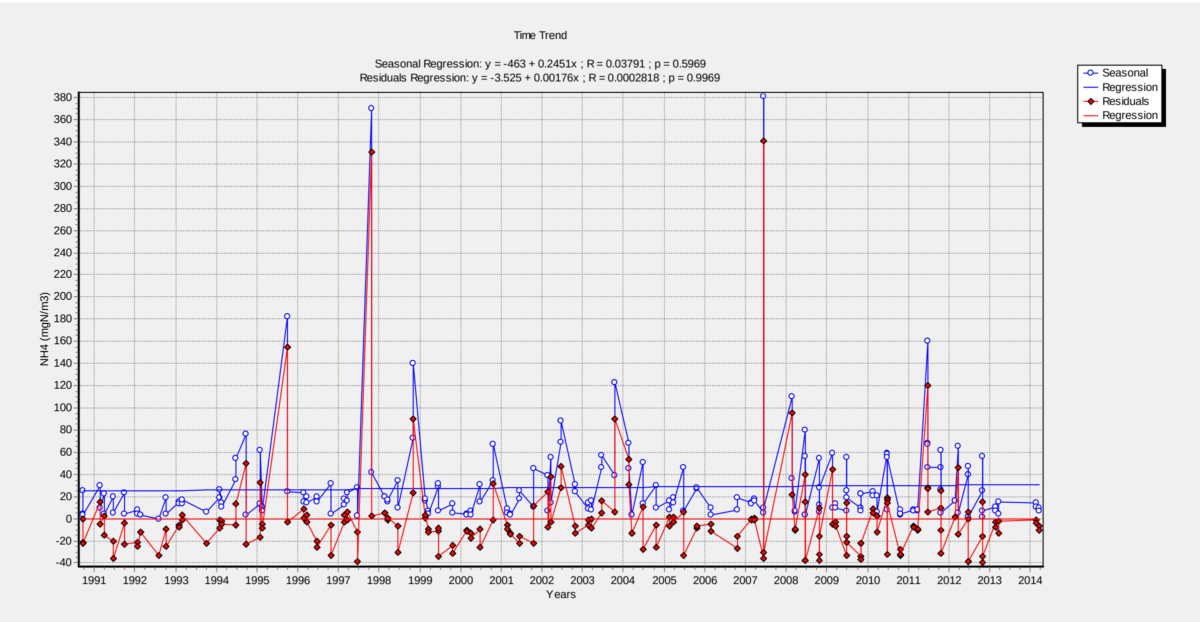
Time Trend
Seasonal Regression: y = 217.9 + -0.1068x ; R = -0.09384 ; p = 0.1382
Residuals Regression: y = 316.4 + -0.1578x ; R = -0.1417 ; p = 0.02473
Seasonal
Regression
Residuals
Regression
TSS (g/m3)
Years

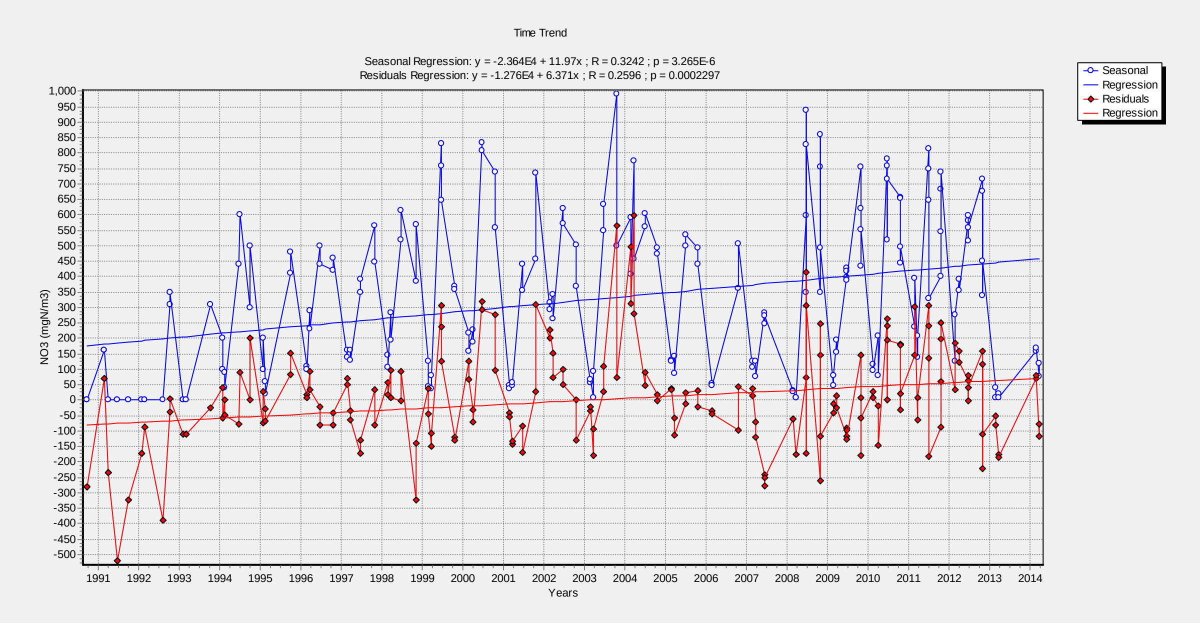


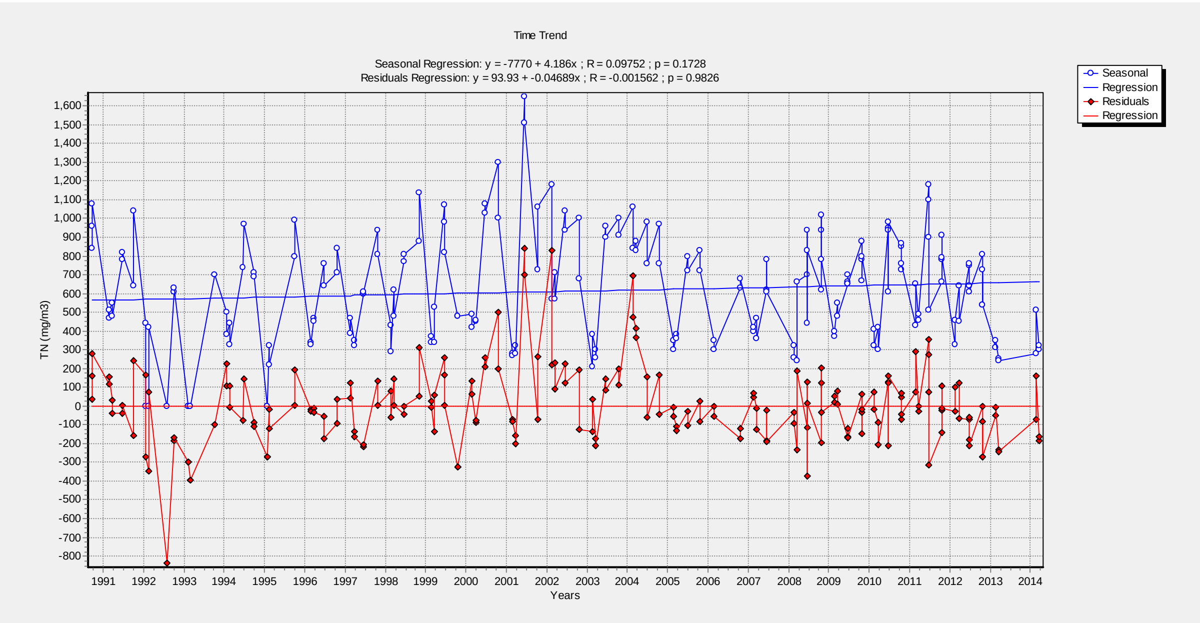
Time Trend
Seasonal Regression: y = 31.62 + -0.007802x ; R = -0.01326 ; p = 0.8575
Residuals Regression: y = 6.976 + -0.003484x ; R = -0.01691 ; p = 0.8188
Seasonal
Regression
Residuals
Regression
Temperature (° C)
Years

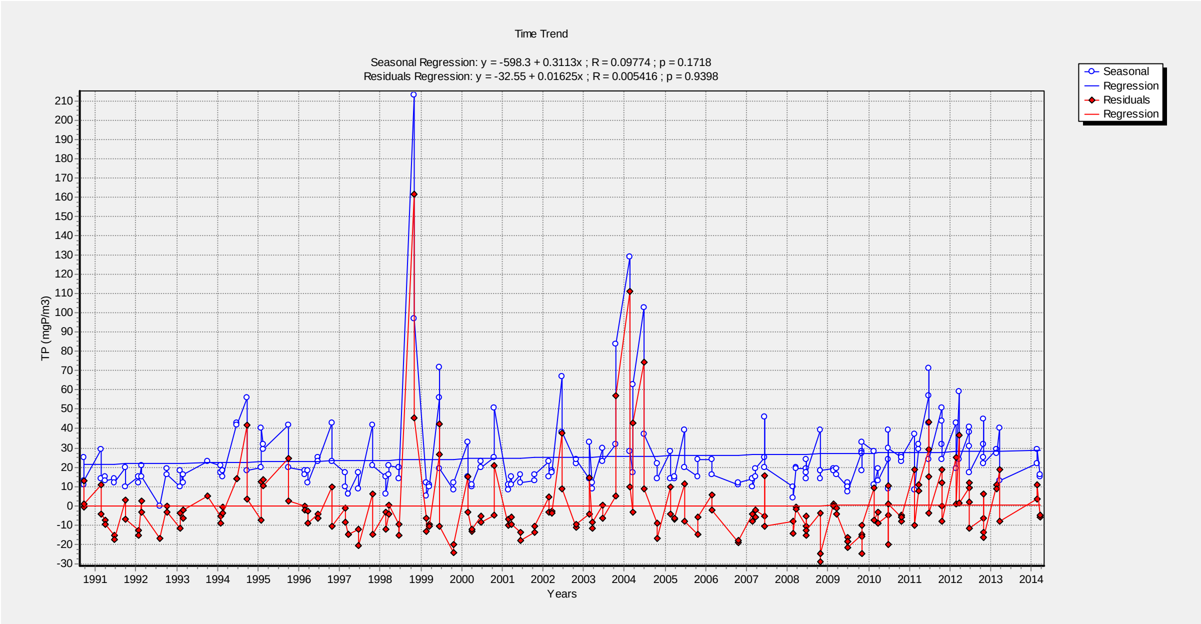
L2 and L3 combined - Nutrients






Time Trend
Seasonal Regression: y = -2.364E4 + 11.97x ; R = 0.3242 ; p = 3.265E-6
Residuals Regression: y = -1.276E4 + 6.371x ; R = 0.2596 ; p = 0.0002297
Seasonal
Regression
Residuals
Regression
NO3 (mgN/m3)
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


Time Trend
Seasonal Regression: y = -7770 + 4.186x ; R = 0.09752 ; p = 0.1728
Residuals Regression: y = 93.93 + -0.04689x ; R = -0.001562 ; p = 0.9826
Seasonal
Regression
Residuals
Regression
TN (mg/m3)
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



Time Trend
Seasonal Regression: y = -598.3 + 0.3113x ; R = 0.09774 ; p = 0.1718
Residuals Regression: y = -32.55 + 0.01625x ; R = 0.005416 ; p = 0.9398
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:** 31/12/2014

Analysis Period	Average	Observed DO	Observed Rate Corrected to 10.1 °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	10.3
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	37.4
01-Jan-1996 - 30-Mar-1996	8.94	27.3	29.5
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	11.0
01-Jan-2000 - 04-Apr-2000	10.12	5.6	5.6
01-Jan-2001 - 31-Mar-2001	11.08	16.4	15.3
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	40.0
01-Jan-2006 - 31-Mar-2006	9.42	19.1	20.0
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	-19.4
01-Jan-2011 - 31-Mar-2011	10.25	24.0	23.7
01-Jan-2012 - 30-Mar-2012	9.84	-5.9	-6.0
01-Jan-2013 - 31-Mar-2013	9.93	13.0	13.2
01-Jan-2014 - 31-Mar-2014	12.39	26.4	22.5
Average	**10.06**	**12.1**	**11.9**

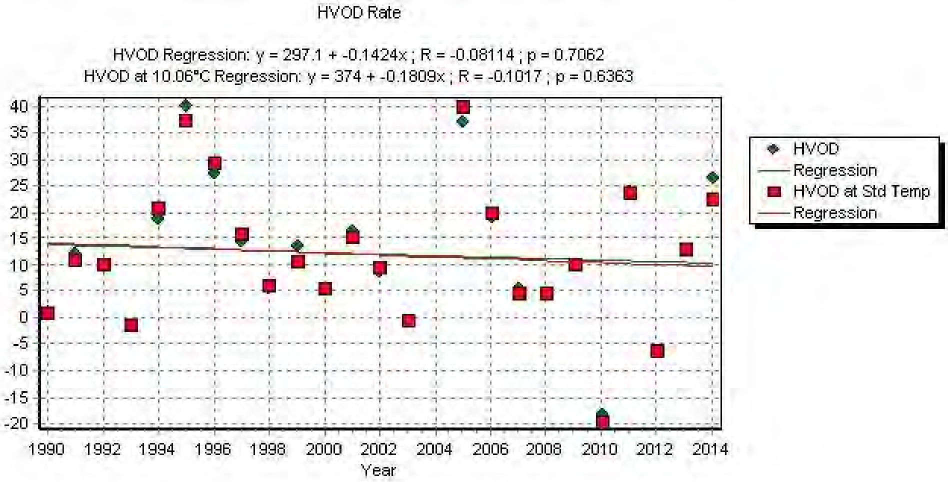
HVOD Analysis

Lake: LAKE ROTORANGI

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

Date From: 01/01/1990 **Date To:** 31/12/2014

Analysis Period	Average	Observed DO	Observed Rate Corrected to 10.1 °C (mg/m3/day)



LAKE ROTORANGI

L2 & L3 1990-2014 (1 Jan 1990 - 31 Dec 2014)

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	(0.00)	(0.02)	(-0.05)	(-0.18)			
Average Over Period	3.12	(2.84)	(25.22)	(615.13)	(11.93)			
Percent Annual Change (%/Year)	**2.24**	**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	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	6.50	3.37	20.50	352.50	4.28	4.09	4.05	4.06	4.12	0.06			
Averages	**3.18**	**2.82**	**24.70**	**599.68**	**3.42**	**4.35**	**4.20**	**4.66**	**4.16**	**0.06**	**0.01**	**0.01**	**0.1978**

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

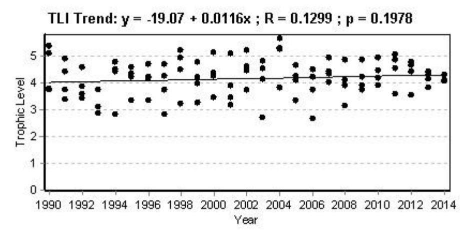
TLI Value = 4.16 ± 0.06 TLI units
TLI Trend = 0.01 ± 0.01 TLI units per year
P-Value = 0.1978

ASSESSMENT:

Eutrophic
No Change

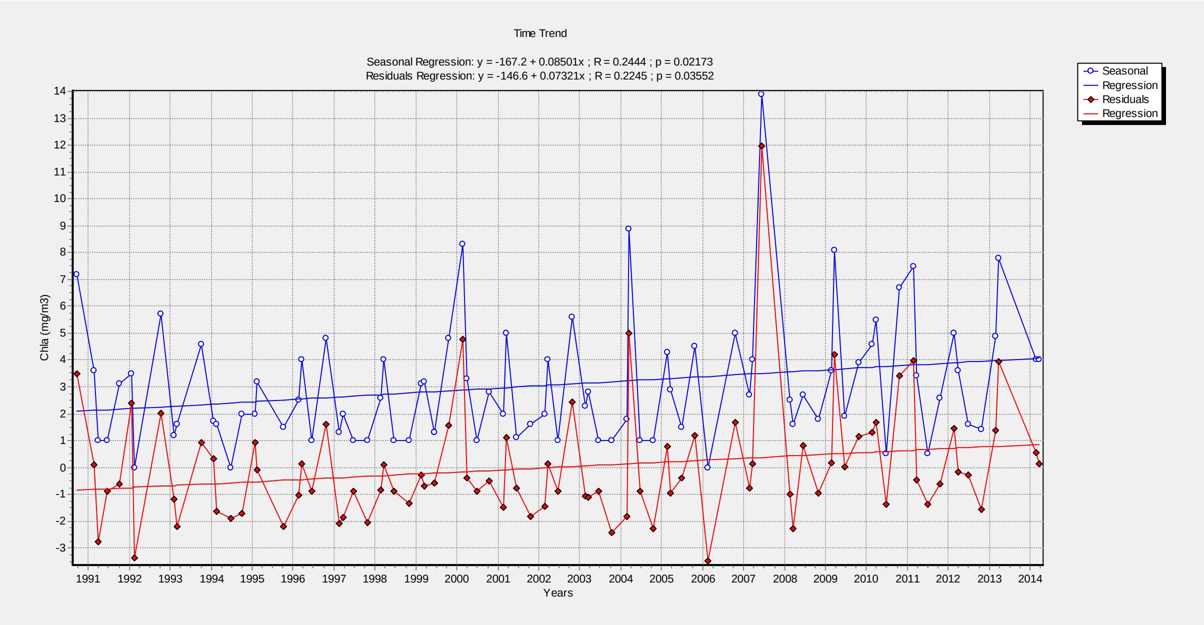
The guide used in the PAC average P-Value evaluation is

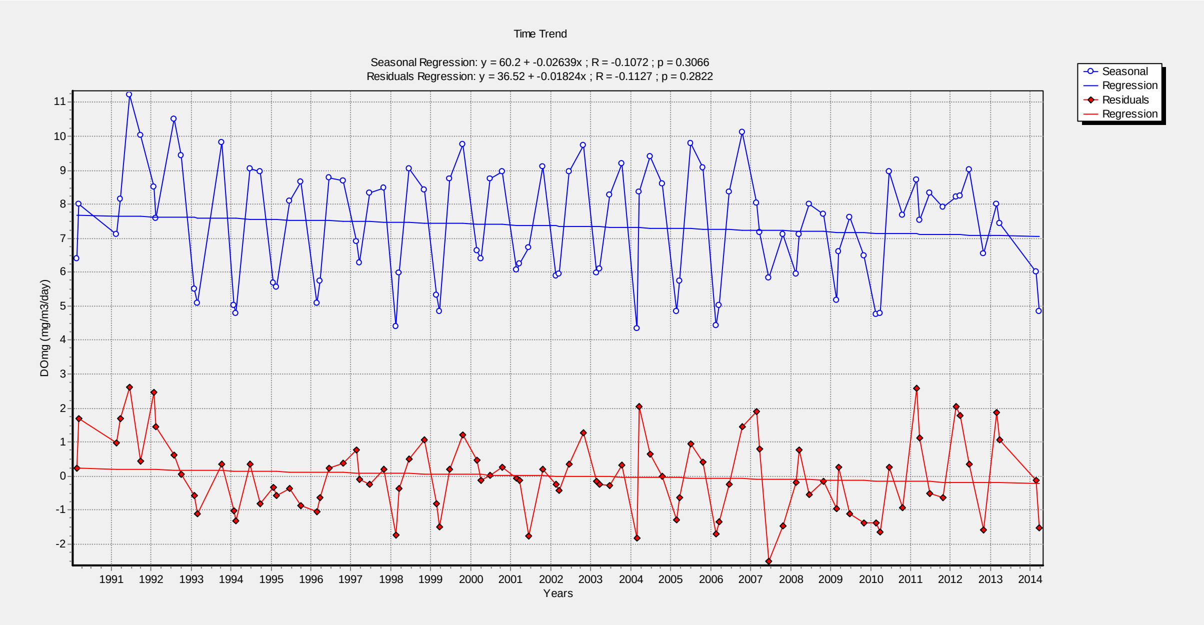
P-Value Range	Interpretation
$P \leq 0.1$	Definite Change
$0.1 < P \leq 0.2$	Probable Change
$0.2 < P \leq 0.3$	Possible Change
$0.3 < P$	No Change

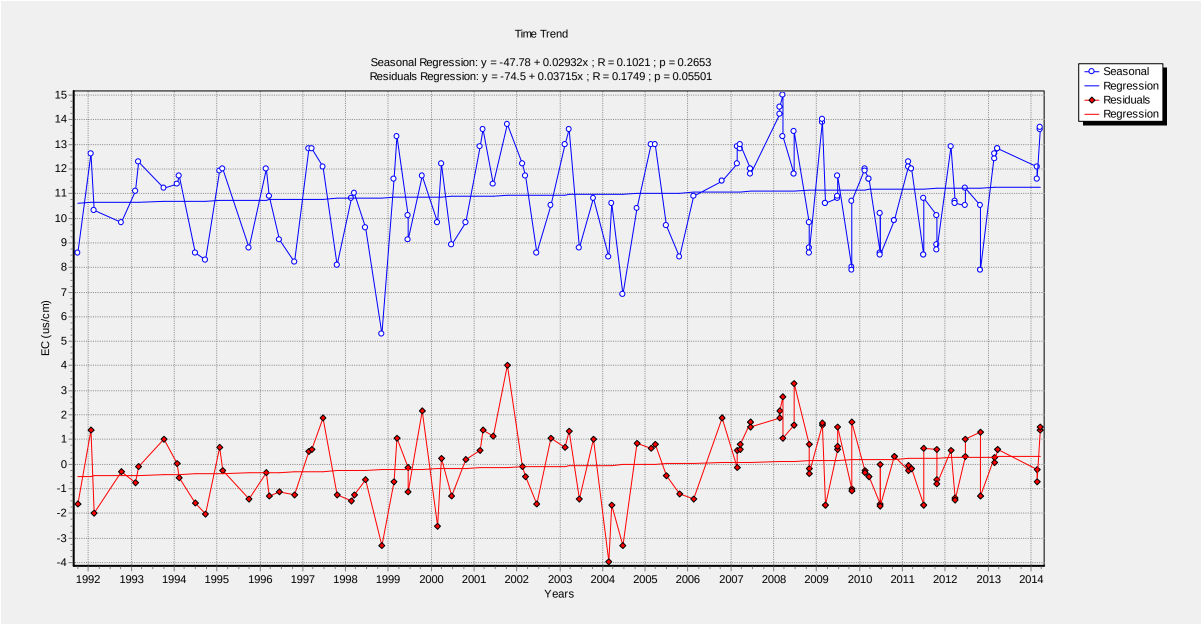


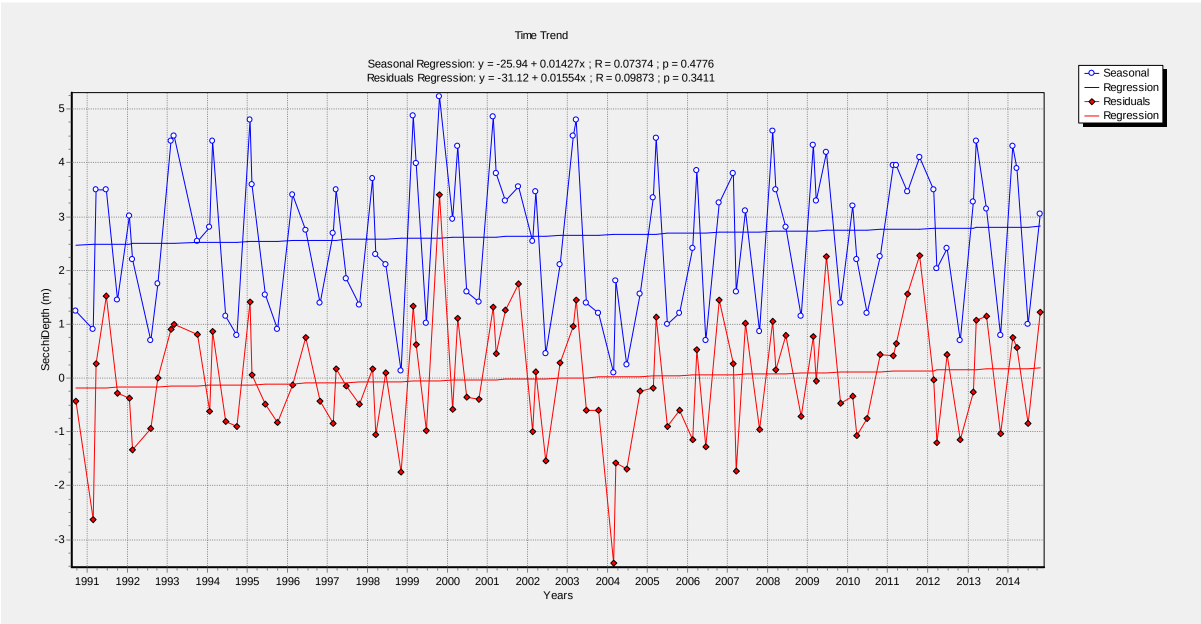
Appendix 3

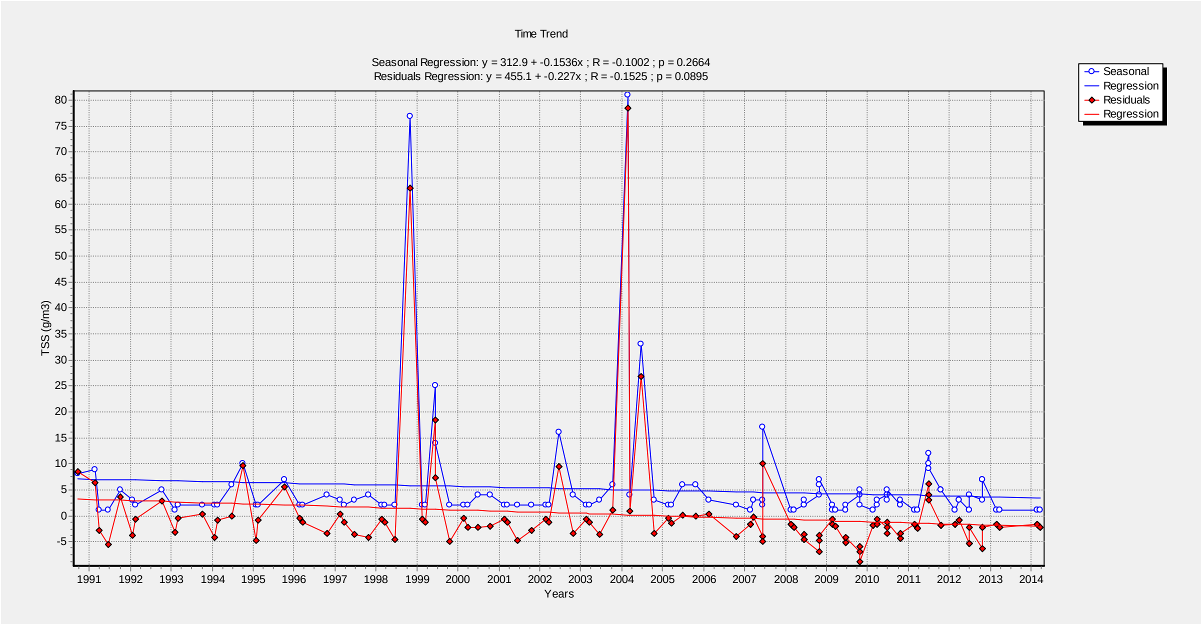
L2 trends – Physical parameters

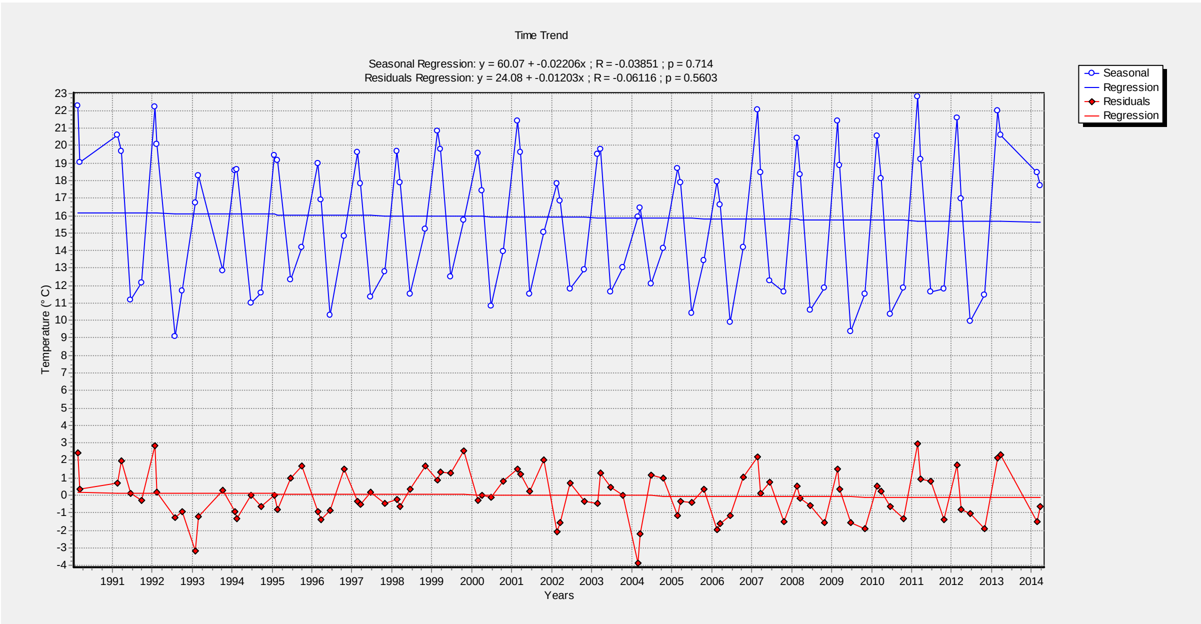




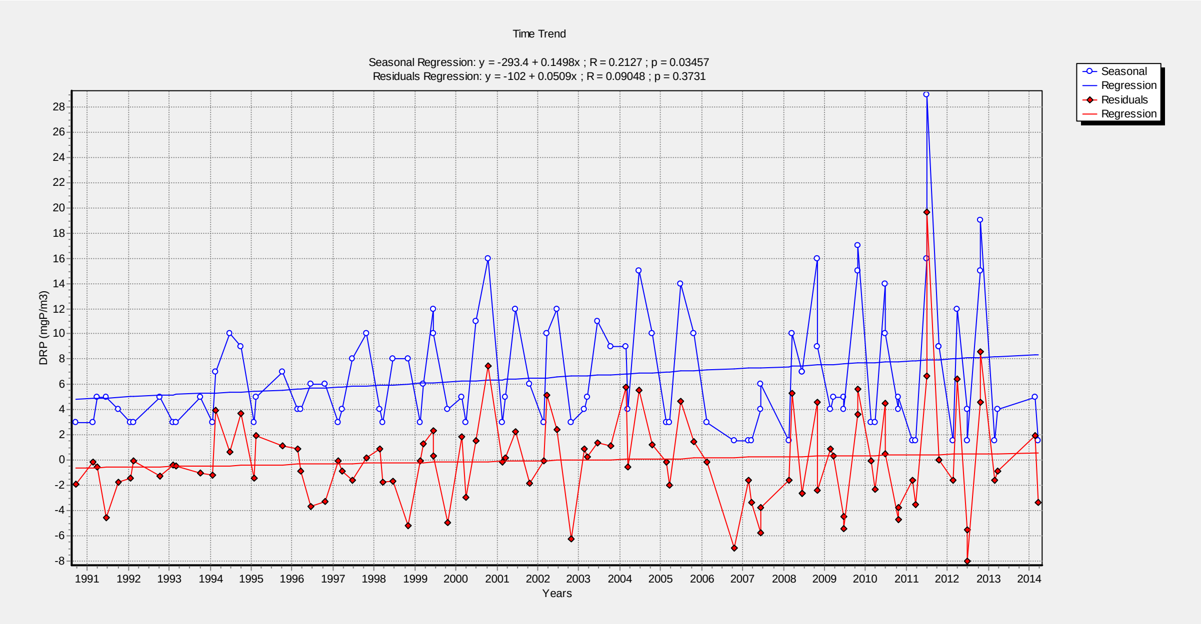

Time Trend
Seasonal Regression: y = -47.78 + 0.02932x ; R = 0.1021 ; p = 0.2653
Residuals Regression: y = -74.5 + 0.03715x ; R = 0.1749 ; p = 0.05501
EC (us/cm)
Years
Seasonal
Regression
Residuals
Regression

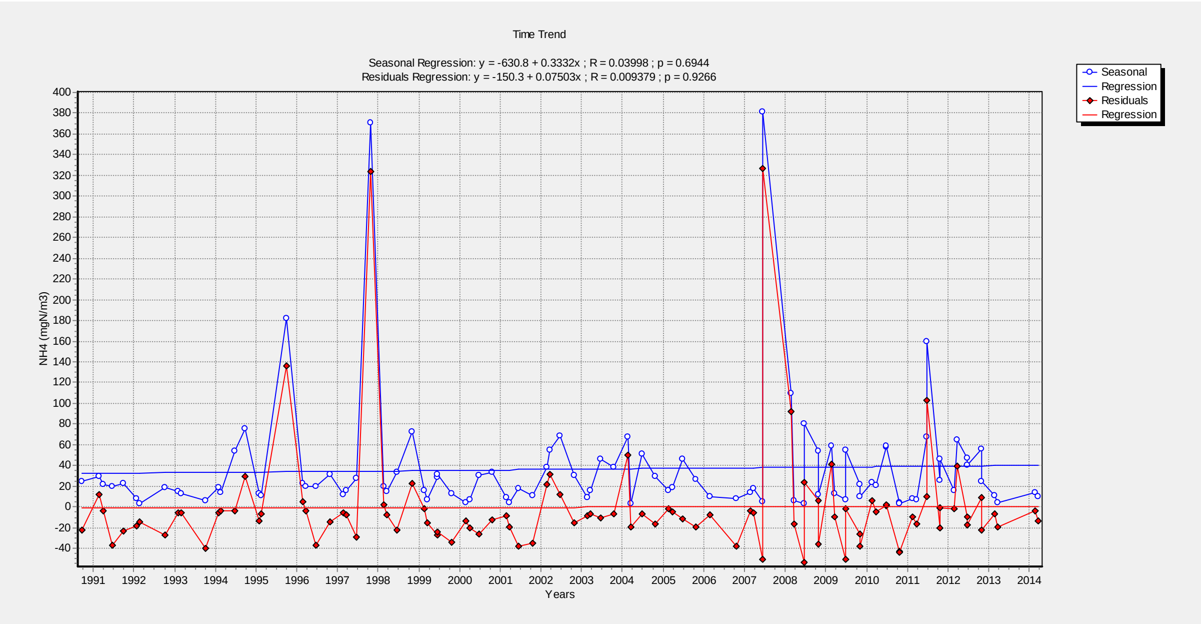

Time Trend
Seasonal Regression: y = -25.94 + 0.01427x ; R = 0.07374 ; p = 0.4776
Residuals Regression: y = -31.12 + 0.01554x ; R = 0.09873 ; p = 0.3411
SecchiDepth (m)
Years
Seasonal
Regression
Residuals
Regression

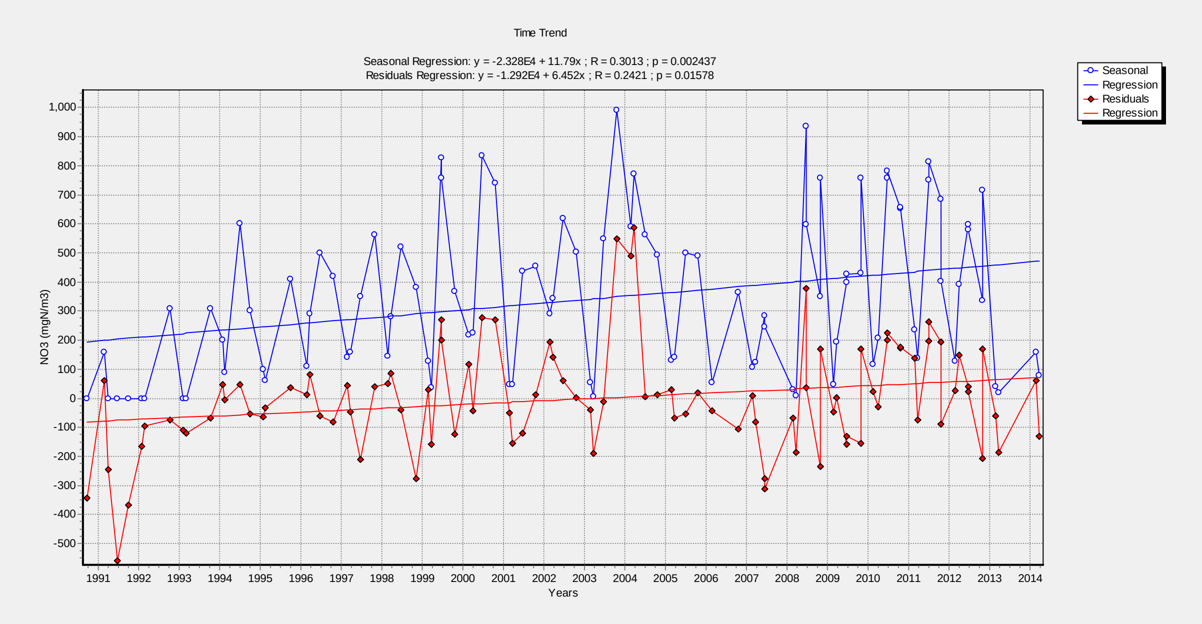

Time Trend
Seasonal Regression: y = 312.9 + -0.1536x ; R = -0.1002 ; p = 0.2664
Residuals Regression: y = 455.1 + -0.227x ; R = -0.1525 ; p = 0.0895
TSS (g/m3)
Years
Seasonal
Regression
Residuals
Regression


Time Trend
Seasonal Regression: y = 60.07 + -0.02206x ; R = -0.03851 ; p = 0.714
Residuals Regression: y = 24.08 + -0.01203x ; R = -0.06116 ; p = 0.5603
Temperature (° C)
Years
Seasonal
Regression
Residuals
Regression

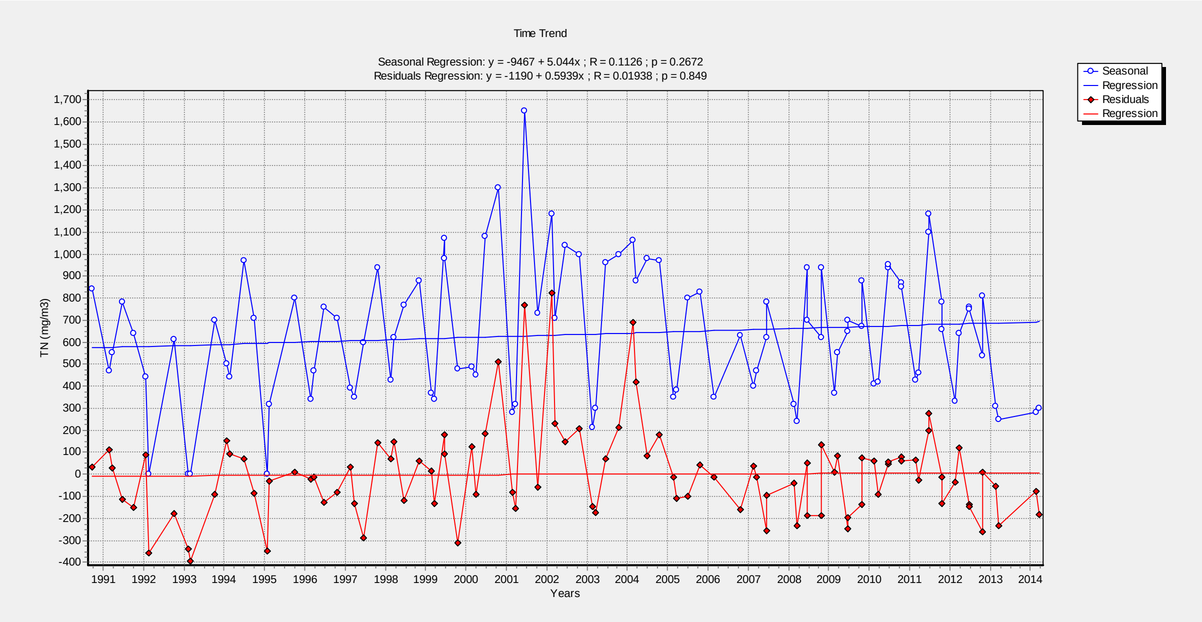
L2 - Nutrients



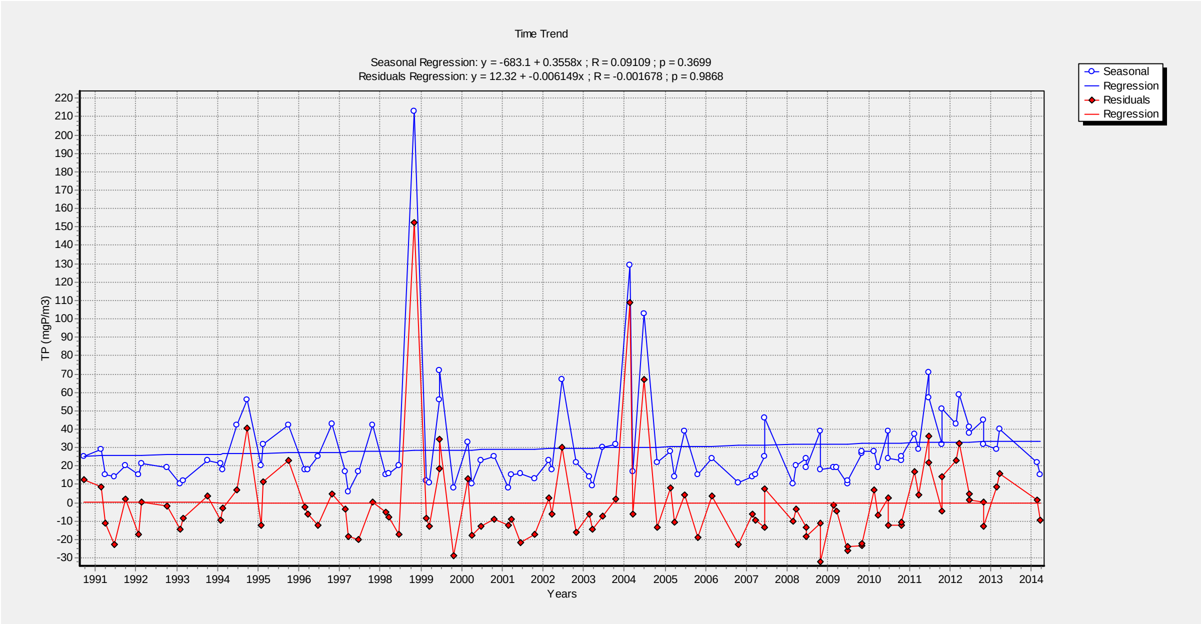




Time Trend
Seasonal Regression: y = -2.328E4 + 11.79x ; R = 0.3013 ; p = 0.002437
Residuals Regression: y = -1.292E4 + 6.452x ; R = 0.2421 ; p = 0.01578
Seasonal
Regression
Residuals
Regression
NO3 (mgN/m3)
1,000
900
800
700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
Years



Time Trend
Seasonal Regression: y = -9467 + 5.044x ; R = 0.1126 ; p = 0.2672
Residuals Regression: y = -1190 + 0.5939x ; R = 0.01938 ; p = 0.849
Seasonal
Regression
Residuals
Regression
TN (mg/m3)
1,700
1,600
1,500
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
-100
-200
-300
-400
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
Years



Time Trend
Seasonal Regression: y = -683.1 + 0.3558x ; R = 0.09109 ; p = 0.3699
Residuals Regression: y = 12.32 + -0.006149x ; R = -0.001678 ; p = 0.9868
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:** 31/12/2014

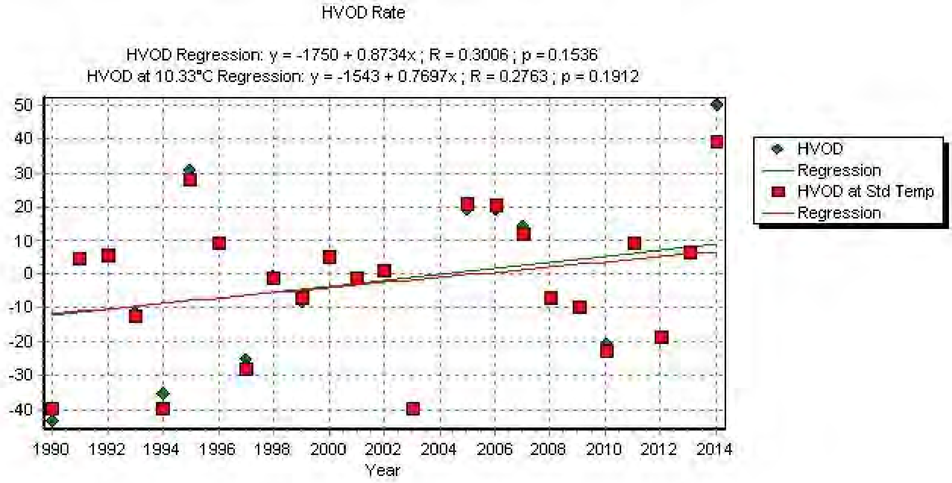
Analysis Period	Average	Observed DO	Observed Rate Corrected to 10.3 °C (mg/m3/day)
01-Jan-1990 - 31-Mar-1990	11.7	-43.3	-39.3
01-Jan-1991 - 31-Mar-1991	11.58	5.1	4.7
01-Jan-1992 - 30-Mar-1992	9.94	5.6	5.8
01-Jan-1993 - 31-Mar-1993	9.4	-11.2	-11.9
01-Jan-1994 - 31-Mar-1994	8.72	-35.2	-39.3
01-Jan-1995 - 31-Mar-1995	11.58	30.7	28.1
01-Jan-1996 - 30-Mar-1996	9.29	8.9	9.6
01-Jan-1997 - 31-Mar-1997	8.82	-24.8	-27.5
01-Jan-1998 - 31-Mar-1998	8.53	-0.6	-0.7
01-Jan-1999 - 31-Mar-1999	13.14	-7.9	-6.5
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	-39.3
01-Jan-2005 - 31-Mar-2005	9.03	19.0	20.8
01-Jan-2006 - 31-Mar-2006	9.51	19.4	20.5
01-Jan-2007 - 31-Mar-2007	12.71	14.5	12.3
01-Jan-2008 - 30-Mar-2008	9.73	-6.5	-6.8
01-Jan-2009 - 31-Mar-2009	10.36	-9.4	-9.4
01-Jan-2010 - 31-Mar-2010	8.96	-20.4	-22.5
01-Jan-2011 - 31-Mar-2011	10.63	9.5	9.3
01-Jan-2012 - 30-Mar-2012	10.11	-18.1	-18.4
01-Jan-2013 - 31-Mar-2013	10.07	6.4	6.5
01-Jan-2014 - 31-Mar-2014	13.86	50.0	39.1
Average	**10.33**	**-1.7**	**-2.5**

HVOD Analysis

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

Date From: 01/01/1990 **Date To:** 31/12/2014

Analysis Period	Average	Observed DO	Observed Rate Corrected to 10.3 °C (mg/m3/day)



LAKE ROTORANGI

L2 1990-2014 (1 Jan 1990 - 31 Dec 2014)

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	(0.02)	(-0.01)	(0.59)	(0.98)			
Average Over Period	3.07	(2.65)	(29.77)	(637.07)	(-3.12)			
Percent Annual Change (%/Year)	**2.28**	**0.00**	**0.00**	**0.00**	**0.00**	**0.46**	**0.46**	**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	4.00	3.06	18.50	290.00	3.75	4.21	3.92	3.80	3.92	0.10			
Averages	**3.23**	**2.62**	**28.96**	**618.49**	**3.42**	**4.45**	**4.37**	**4.71**	**4.24**	**0.07**	**0.01**	**0.01**	**0.5468**

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 = 0.46 ± 0.46 % per year
P-Value = 0.37

TLI Value = 4.24 ± 0.07 TLI units
TLI Trend = 0.01 ± 0.01 TLI units per year
P-Value = 0.5468

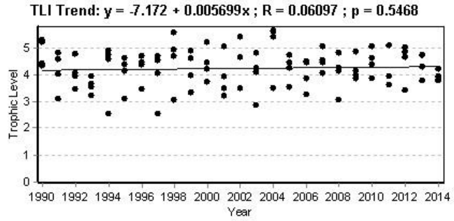
ASSESSMENT:

Eutrophic
No Change

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

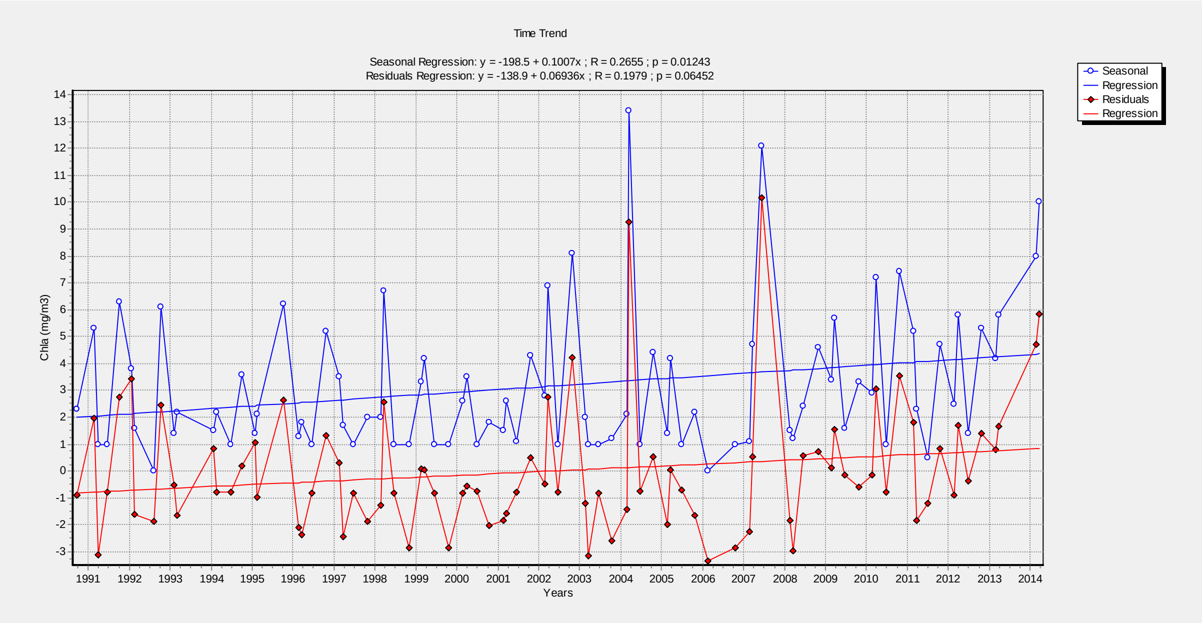
P-Value Range	Interpretation
P ≤ 0.1	Definite Change
0.1 < P ≤ 0.2	Probable Change
0.2 < P ≤ 0.3	Possible Change
0.3 < P	No Change

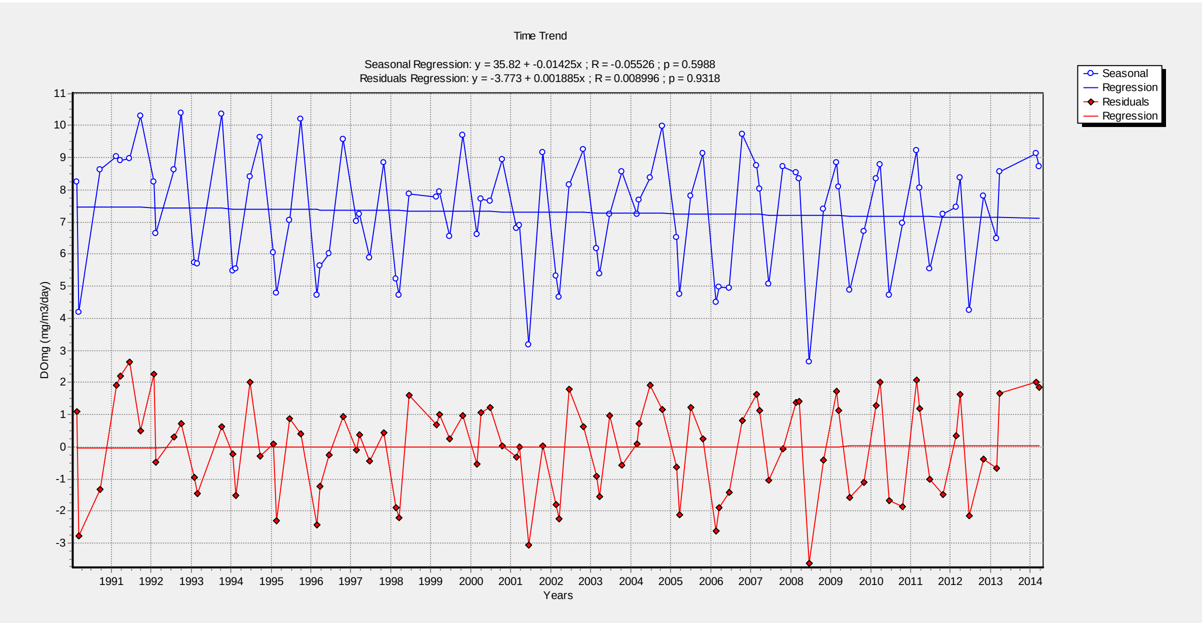
TLI Trend: y = -7.172 + 0.005699x ; R = 0.06097 ; p = 0.5468

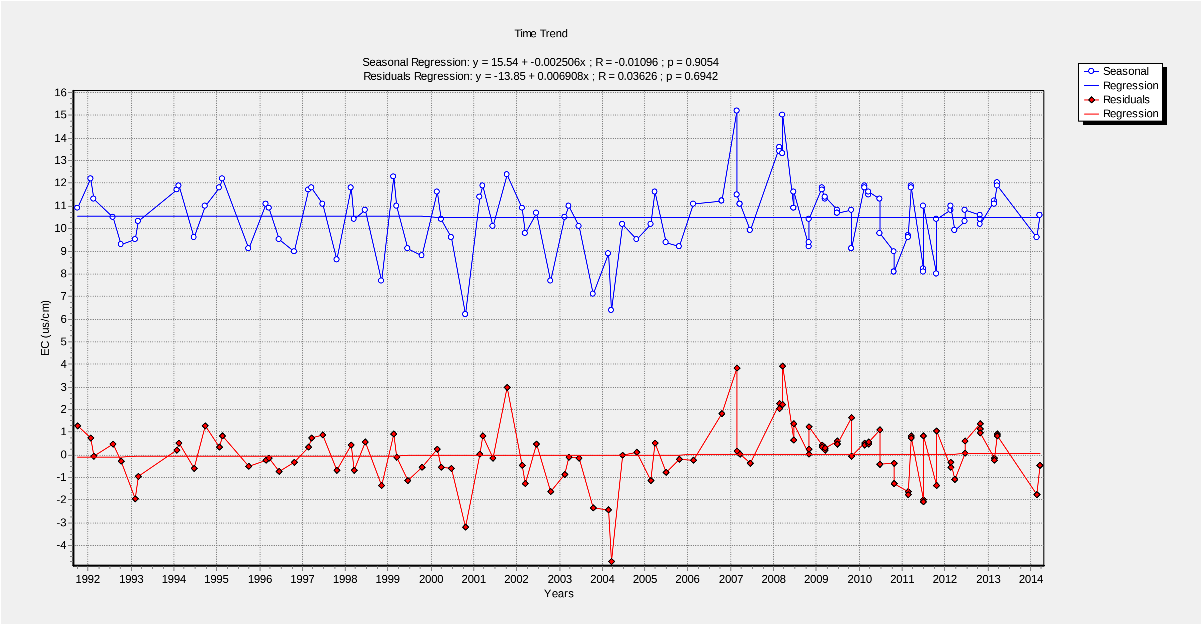


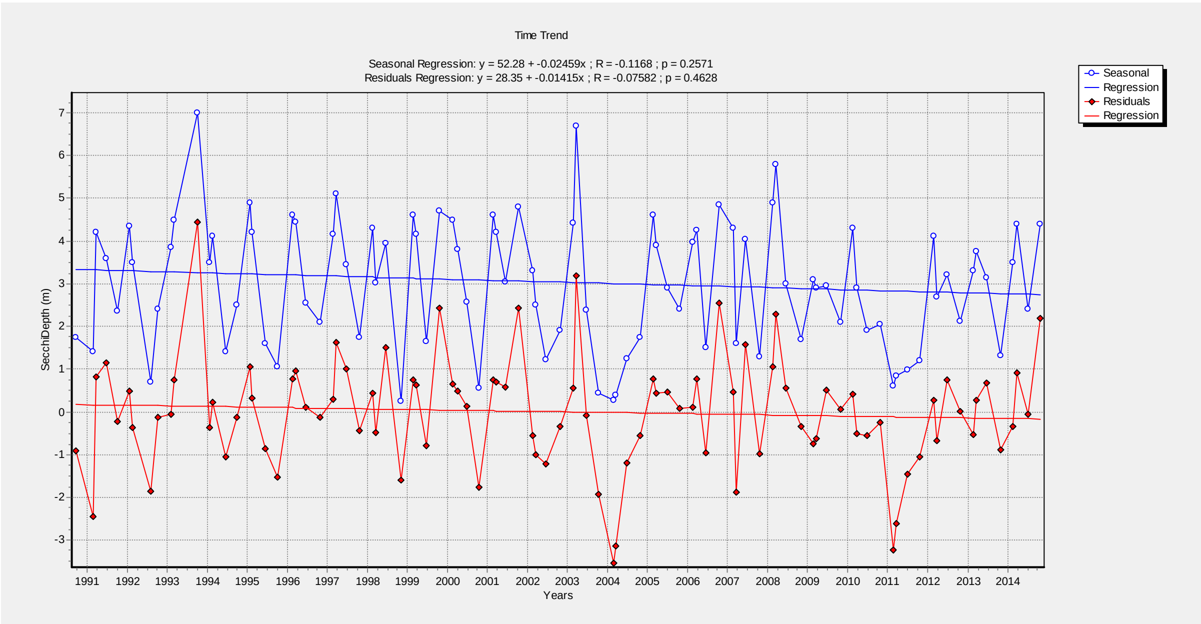
Appendix 4

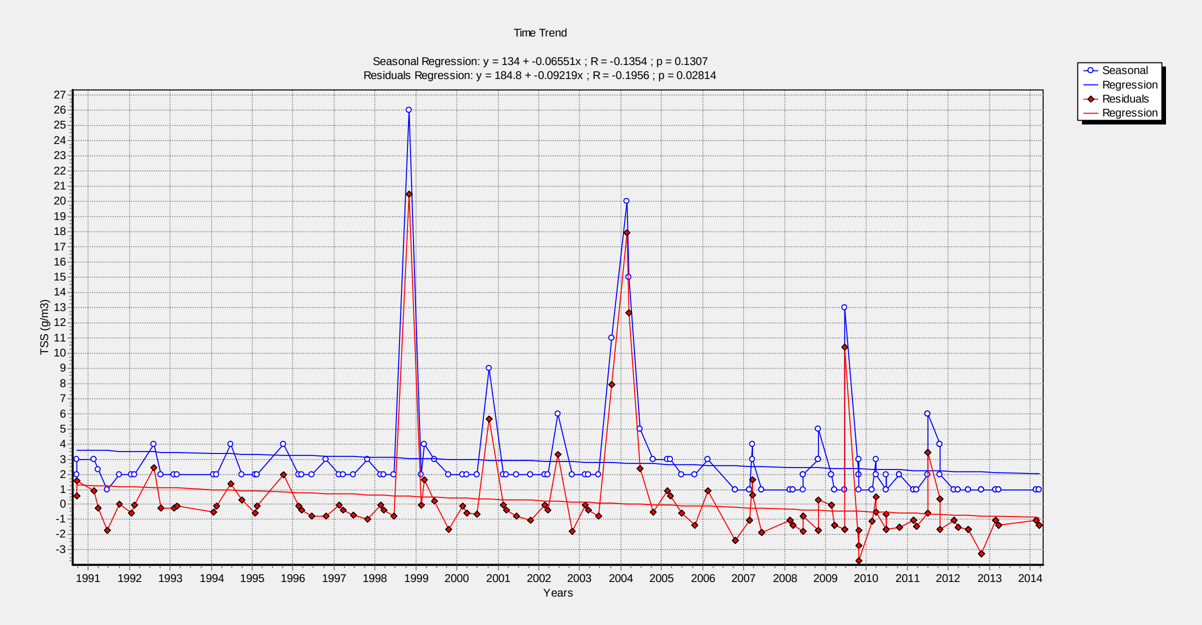
L3 – Physical parameters

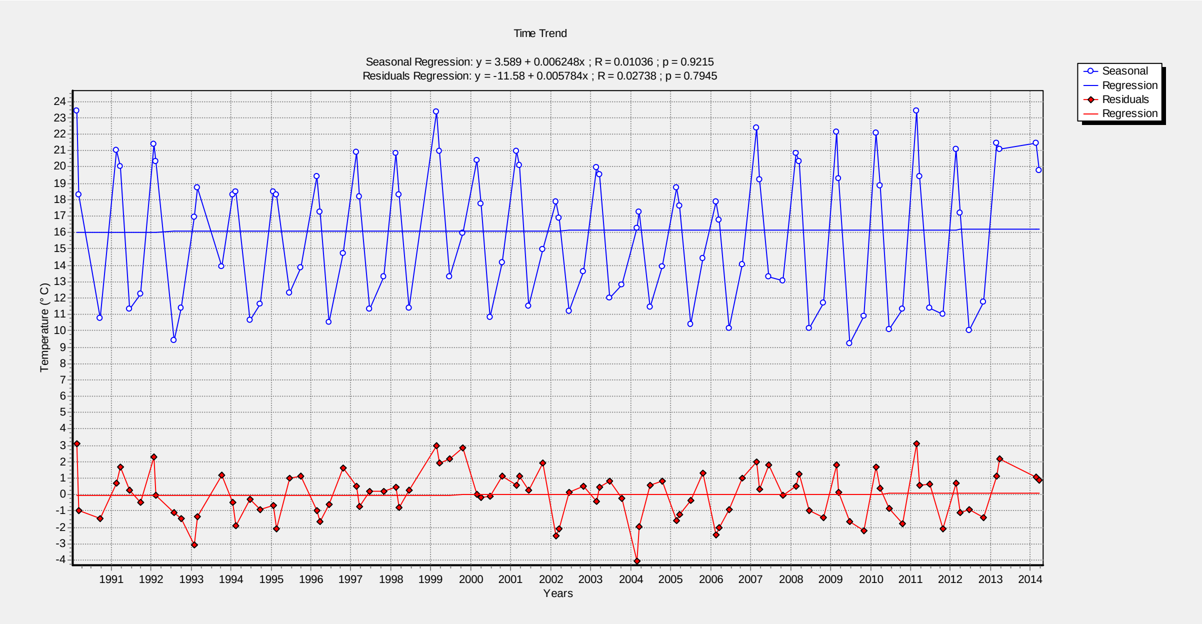




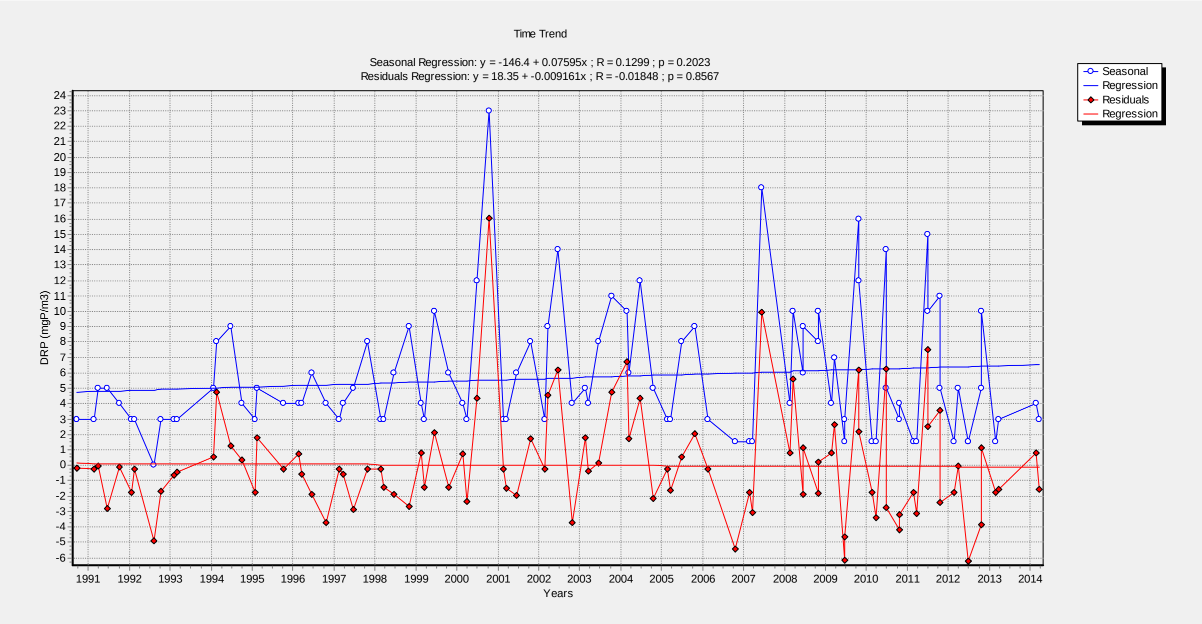

Time Trend
Seasonal Regression: y = 15.54 + -0.002506x ; R = -0.01096 ; p = 0.9054
Residuals Regression: y = -13.85 + 0.006908x ; R = 0.03626 ; p = 0.6942
Seasonal
Regression
Residuals
Regression
EC (us/cm)
Years

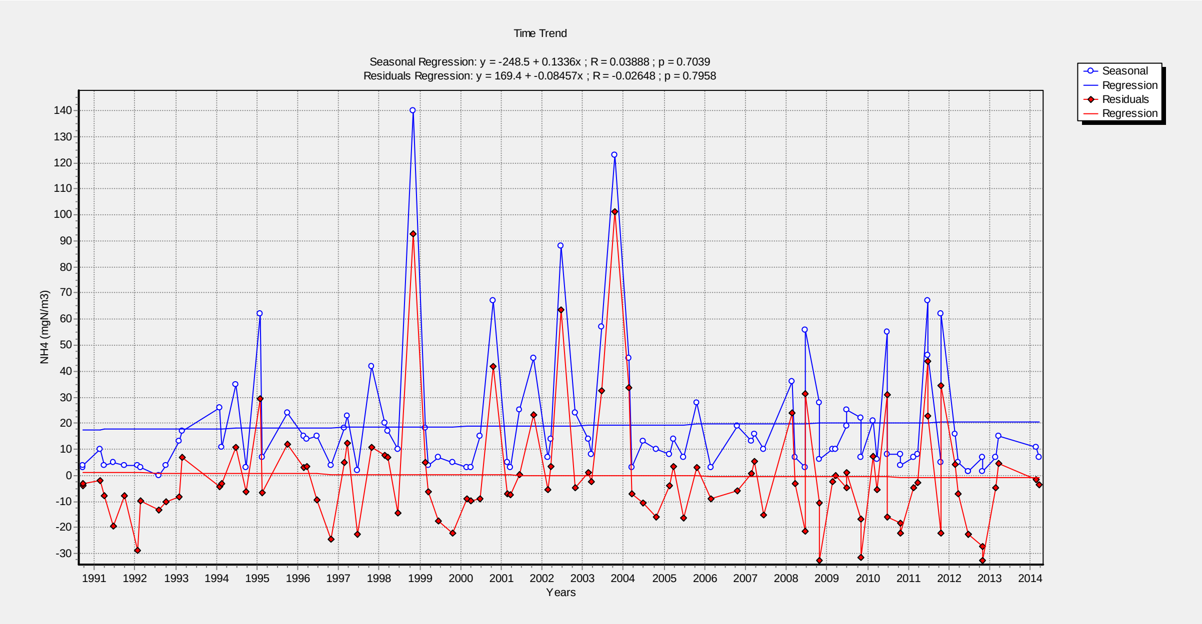

Time Trend
Seasonal Regression: y = 52.28 + -0.02459x ; R = -0.1168 ; p = 0.2571
Residuals Regression: y = 28.35 + -0.01415x ; R = -0.07582 ; p = 0.4628
Seasonal
Regression
Residuals
Regression
SecchiDepth (m)
Years

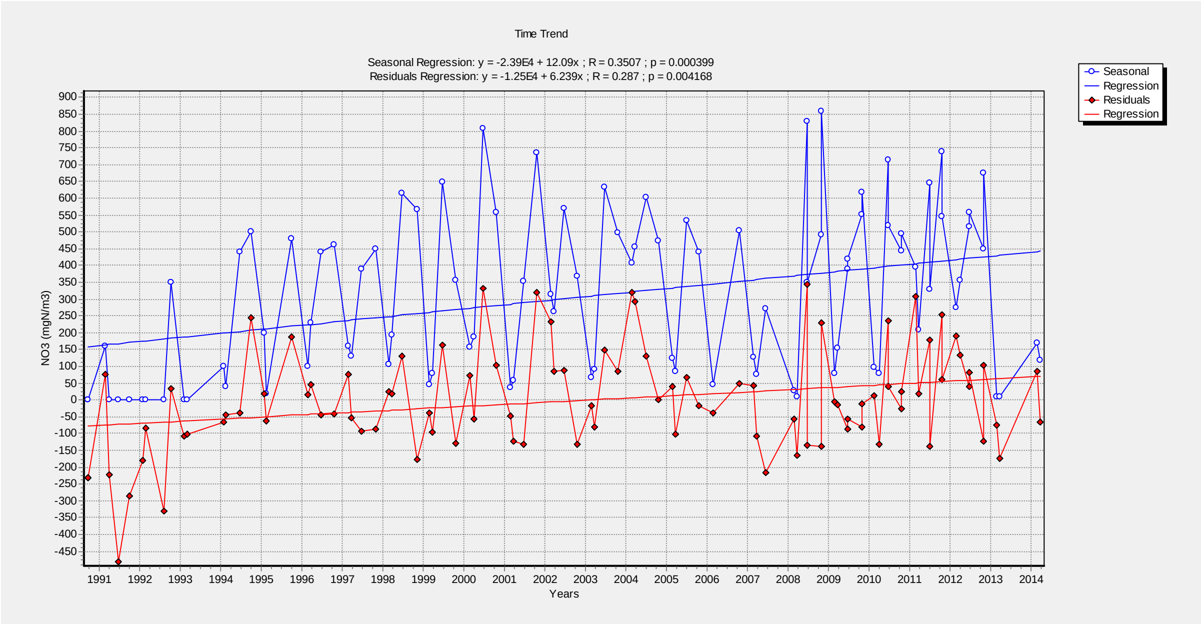

Time Trend
Seasonal Regression: y = 134 + -0.06551x ; R = -0.1354 ; p = 0.1307
Residuals Regression: y = 184.8 + -0.09219x ; R = -0.1956 ; p = 0.02814
TSS (g/m3)
Years
Seasonal
Regression
Residuals
Regression


Time Trend
Seasonal Regression: y = 3.589 + 0.006248x ; R = 0.01036 ; p = 0.9215
Residuals Regression: y = -11.58 + 0.005784x ; R = 0.02738 ; p = 0.7945
Temperature (° C)
Years
Seasonal
Regression
Residuals
Regression

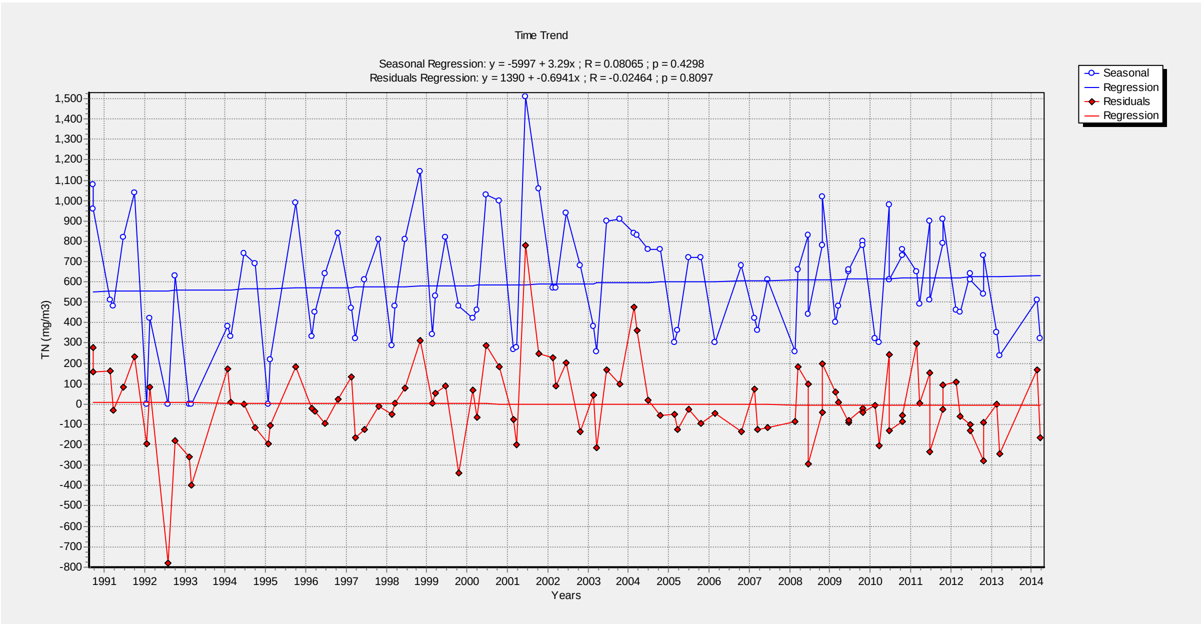
L3 - Nutrients



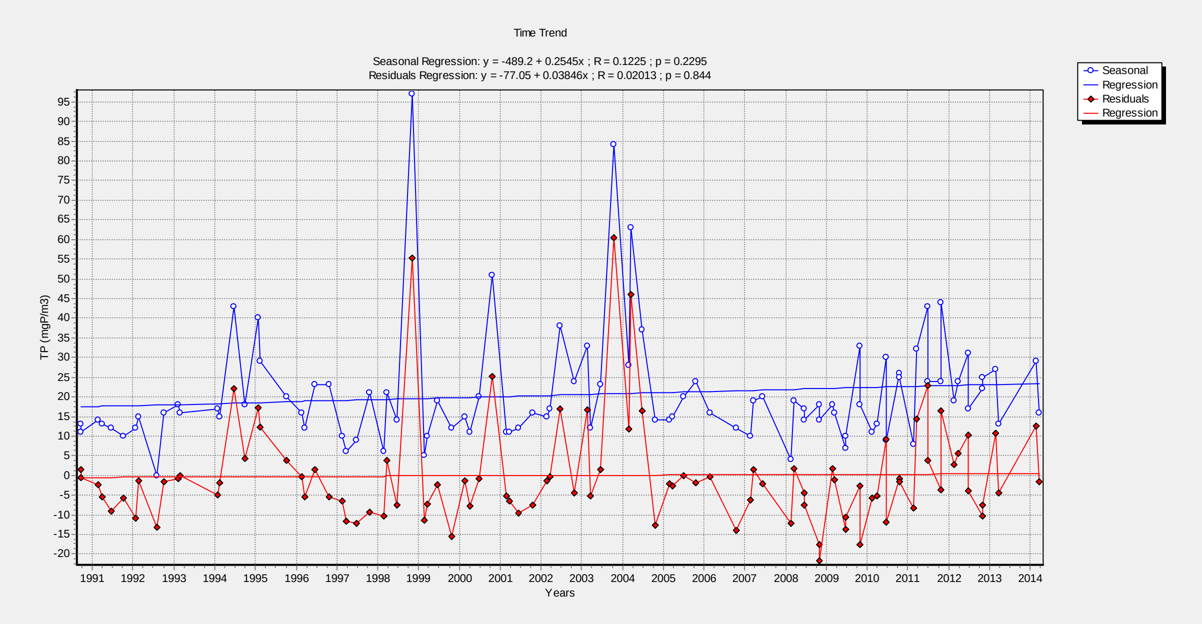




Time Trend
Seasonal Regression: y = -2.39E4 + 12.09x ; R = 0.3507 ; p = 0.000399
Residuals Regression: y = -1.25E4 + 6.239x ; R = 0.287 ; p = 0.004168
Seasonal
Regression
Residuals
Regression
NO3 (mgN/m3)
Years



Time Trend
Seasonal Regression: y = -5997 + 3.29x ; R = 0.08065 ; p = 0.4298
Residuals Regression: y = 1390 + -0.6941x ; R = -0.02464 ; p = 0.8097
Seasonal
Regression
Residuals
Regression
TN (mg/m3)
Years



Time Trend
Seasonal Regression: y = -489.2 + 0.2545x ; R = 0.1225 ; p = 0.2295
Residuals Regression: y = -77.05 + 0.03846x ; R = 0.02013 ; p = 0.844
TP (mgP/m3)
Years
Seasonal
Regression
Residuals
Regression

HVOD Analysis

Lake: LAKE ROTORANGI

Stations: L3 (Dam)

Date From: 01/01/1990 **Date To:** 31/12/2014

Analysis Period	Average	Observed DO	Observed Rate Corrected to 9.8 °C (mg/m3/day)
01-Jan-2014 - 31-Mar-2014	10.92	2.8	2.6
01-Jan-1990 - 31-Mar-1990	9.31	45.4	47.1
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	9.1
01-Jan-1994 - 31-Mar-1994	8.62	16.1	17.5
01-Jan-1995 - 31-Mar-1995	10.62	49.8	47.1
01-Jan-1996 - 30-Mar-1996	8.59	45.7	49.8
01-Jan-1997 - 31-Mar-1997	8.51	29.1	31.9
01-Jan-1998 - 31-Mar-1998	8.09	11.8	13.3
01-Jan-1999 - 31-Mar-1999	13.49	35.3	27.4
01-Jan-2000 - 04-Apr-2000	10.0	5.8	5.8
01-Jan-2001 - 31-Mar-2001	11.39	34.0	30.5
01-Jan-2002 - 31-Mar-2002	8.6	16.5	18.0
01-Jan-2003 - 31-Mar-2003	9.47	-0.8	-0.8
01-Jan-2005 - 31-Mar-2005	8.86	55.0	58.8
01-Jan-2006 - 31-Mar-2006	9.34	18.8	19.5
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	30.0
01-Jan-2010 - 31-Mar-2010	8.98	-15.6	-16.5
01-Jan-2011 - 31-Mar-2011	9.88	38.4	38.3
01-Jan-2012 - 30-Mar-2012	9.57	6.3	6.4
01-Jan-2013 - 31-Mar-2013	9.78	19.7	19.8
Average	**9.83**	**20.8**	**20.9**

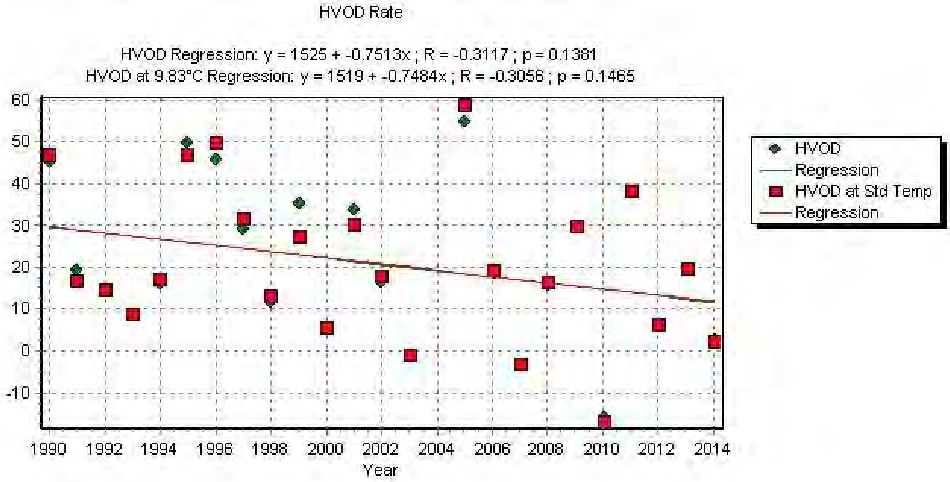
HVOD Analysis

Lake: LAKE ROTORANGI

Stations: L3 (Dam)

Date From: 01/01/1990 **Date To:** 31/12/2014

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



LAKE ROTORANGI

L3 1990-2014 (1 Jan 1990 - 31 Dec 2014)

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)	(0.04)	(-0.69)	(-0.79)			
Average Over Period	(3.16)	(3.04)	(20.62)	(592.96)	(22.75)			
Percent Annual Change (%/Year)	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**1.00**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Jan 1990 - Dec 1990	2.30	1.75	12.00	1,020.00	3.14	4.88	3.37		3.80	0.55			
Jan 1991 - Dec 1991	3.40	2.89	12.25	712.50	3.57	4.28	3.40		3.75	0.27			
Jan 1992 - Dec 1992	2.87	2.74	10.75	262.50	3.38	4.34	3.23		3.65	0.35			
Jan 1993 - Dec 1993	1.80	5.12	17.00	0.00	2.87	3.56	3.81		3.41	0.28			
Jan 1994 - Dec 1994	2.07	2.87	23.25	535.00	3.03	4.28	4.21		3.84	0.41			
Jan 1995 - Dec 1995	3.23	2.94	29.67	403.33	3.51	4.26	4.52		4.10	0.30			
Jan 1996 - Dec 1996	2.32	3.42	18.50	565.00	3.15	4.07	3.92		3.71	0.28			
Jan 1997 - Dec 1997	2.05	3.61	11.50	552.50	3.01	4.00	3.32		3.44	0.29			
Jan 1998 - Dec 1998	2.67	2.89	34.50	680.00	3.31	4.28	4.71		4.10	0.42			
Jan 1999 - Dec 1999	2.37	3.77	11.50	542.50	3.17	3.95	3.32		3.48	0.24			
Jan 2000 - Dec 2000	2.22	2.86	24.25	727.50	3.10	4.29	4.26		3.88	0.39			
Jan 2001 - Dec 2001	2.38	4.16	12.50	780.00	3.17	3.83	3.42		3.47	0.19			
Jan 2002 - Dec 2002	4.70	2.23	23.50	690.00	3.93	4.59	4.22		4.25	0.19			
Jan 2003 - Dec 2003	1.30	3.49	38.00	612.50	2.51	4.05	4.83		3.80	0.68			
Jan 2004 - Dec 2004	5.22	0.92	35.50	797.50	4.04	5.63	4.74		4.81	0.46			
Jan 2005 - Dec 2005	2.20	3.45	18.25	525.00	3.09	4.06	3.90		3.68	0.30			
Jan 2006 - Dec 2006	0.50	3.64	14.00	490.00	1.46	3.99	3.56		3.00	0.78			
Jan 2007 - Dec 2007	4.75	2.81	21.00	592.50	3.94	4.31	4.08		4.11	0.11			
Jan 2008 - Dec 2008	2.43	3.85	14.33	665.00	3.20	3.92	3.59		3.57	0.21			
Jan 2009 - Dec 2009	3.50	2.76	17.00	628.33	3.60	4.33	3.81		3.91	0.22			
Jan 2010 - Dec 2010	4.63	2.79	19.00	616.67	3.91	4.32	3.95		4.06	0.13			
Jan 2011 - Dec 2011	3.17	0.91	29.17	708.33	3.49	5.64	4.50		4.54	0.62			
Jan 2012 - Dec 2012	3.75	3.03	23.00	571.67	3.68	4.22	4.19		4.03	0.18			
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			
Averages	**3.19**	**3.02**	**20.52**	**575.53**	**3.36**	**4.29**	**3.96**		**3.87**	**0.07**	**0.02**	**0.01**	**0.0659**

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value

SUMMARY:

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

TLI Value = 3.87 ± 0.07 TLI units
TLI Trend = 0.02 ± 0.01 TLI units per year
P-Value = 0.0659

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