State of the Environment Monitoring of Lake Rotorangi water quality and biological programme

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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 for hydro-electric power generation. During the process of obtaining planning consents, it was recognised that, although a regionally significant recreational resource would be formed, considerable environmental impacts might also occur. Consequently, a comprehensive monitoring programme was developed and implemented for the lake. This report presents the results of the twenty-seventh and twenty-eighth years of this monitoring.

Four water quality sampling surveys were performed at two sites each year during the 2016-2017 and 2017-2018 periods. The first of the two sites surveyed is located in the mid reaches of the lake, while the second site is located nearer to the dam.

Changes in thermal stratification during the year in both periods 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 surveys, and was well developed during the late summer-autumn at the mid and lower lake sites, with dissolved oxygen depletion measured in the lower waters of the hypolimnion at both sites. Oxygen depletion remained evident in winter at the lower lake site. Lake overturn had not occurred completely at the lower lake site by the time of the winter surveys, although water temperatures were uniform throughout the water column. These conditions have been typical of this reservoir-type lake on most occasions to date.

During the monitoring period, phytoplankton richnesses (diversity) were low to moderate, coincident with low to moderate chlorophyll-a levels. The main limiting factors for communities within the lake probably continue to be plant nutrient availability and frequency of river freshes. A very sparse macroinvertebrate fauna has been found amongst the fine sediments of the deeper lake sites where only those taxa able to tolerate lengthy periods of very low dissolved oxygen levels have been recorded.

An autumn 2018 macrophyte survey identified the oxygen weed *Egeria densa* as the dominant macrophyte in the lower part of the lake. The other species recorded as dominant was *Ceratophyllum demersum* (hornwort), in parts of the mid-section of the lake. *Lagarosiphon major*, which had been recorded in all previous surveys, was not found, possibly as a result of the high turbidity at the time of the survey. Hornwort, which was first recorded in the 2012 survey and had increased markedly at the time of the 2015 survey, was not recorded to have extended beyond the mid-section in the 2018 survey. It had been predicted 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 hydro-electric 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 2020-2021 period.

Lake condition, in terms of lake productivity, continued to be within the category of mesotrophic to possibly mildly eutrophic (mildly nutrient enriched). However, taking into account the influence of suspended sediment in this reservoir, and the moderately low chlorophyll levels, the classification is more appropriately mesotrophic. Previous trending of these water quality data over time found a very slow rate of increase in trophic level. An update of the trend report (for the period 1990-2017) 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 2018-2019 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 comprises a number of individual monitoring activities, many of which are undertaken and managed on an annual basis (from 1 July to 30 June). For these annual monitoring activities, summary reports are produced following the end of each monitoring year. Where possible, individual consent monitoring programmes have been integrated with the SEM programme to save duplication of effort and minimise costs (as in the case of the TrustPower Ltd. Patea Dam HEP programme in the past). The purpose of annual SEM reports is to summarise monitoring activity results for the year and provide a brief interpretation of these results.

Annual SEM reports act as 'building blocks' towards the preparation of the regional state of the environment report every five years. The Council's first, or baseline, state of the environment report was prepared in 1996 (TRC, 1996a), summarising the region's progress in managing environmental quality in Taranaki over the past two decades. The second report (for the period 1995-2000) was published in 2003 (TRC, 2003a). The third State of the Environment report (for the period 1995 to 2007) was published in 2009 (TRC, 2009a) and included trend reporting. The fourth report (for the period 1995 to 2013) was published in 2015 (TRC, 2015a). The provision of appropriate statistical software now allows regular reporting on trends in environmental quality over time where there has been an accumulation of a comprehensive dataset of sufficient duration to permit a meaningful analysis to be undertaken (i.e. minimum of 10 years).

1.2 Background

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

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

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

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

Following the publication of the initial monitoring report, the Taranaki Catchment Board, in conjunction with the Egmont Electric Power Board, considered the frequency and nature of the future monitoring programme for Lake Rotorangi. Given the unexpectedly favourable way in which the lake had settled down, it was decided that the monitoring programme should be scaled down to a residual level involving less frequent sampling, yet be capable of maintaining an on-going measure of lake conditions. These scaled-down programmes have now operated since 1988 and have been the subject of twenty-six Annual Reports and four subsequent state of the environment reports. An opportunity was also taken (in mid 1995) to review the appropriateness of the monitoring programme and the results obtained over the seven years of its operation in this format. NIWA (as consultant to the Council) provided the assessment and suggested minor changes to the monitoring programme to enable additional long term seasonal trend analysis to be performed, providing a more powerful capability for determining possible changes in trophic condition in the lake (Burns, 1995). An additional review of the results of the ten years of monitoring was undertaken by Lakes Consultancy (Burns, 1999), who also assessed the trophic status of Lake Rotorangi (see Section 1.4). Lake water quality trends for the period 1990–2006 were also re-analysed by Lakes Consultancy (Burns, 2006) as a component of a consent renewal process which was progressed during the 2007-2010 period. The Council has subsequently re-analysed the water quality trends over the 1990-2017 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 and June 2015 provided some information in this respect (TRC, 1990, TRC 2016). The impacts of minor freshes have been reported from time-to-time (TRC 1992; TRC 1993; TRC 1995).

The Patea Catchment above the dam (including the Mangaehu sub catchment) covers an area of 86,944.3 ha, with an urban area of 840.9 ha (1%). Riparian plans have been prepared for an area of 22,048.4 ha (25% of catchment). As at June 2018, some 231 riparian plans have been prepared by the Council in relation to properties within the Patea River sub-catchment. An additional three plans have been produced for properties in the Mangaehu River sub-catchment, upstream of the lake. Within these plans, some 1008 km of Patea riverbank [71% of the total banks' length] and 26 km of Mangaehu stream banks [54%] currently have adequate riparian protection provided on the properties covered by the plans. This represents an increase of 143 km in the Patea catchment and 7 km in the Mangaehu catchment over the past three years. Outside of the properties covered by riparian plans there are a further 51% and 98% of streambanks in the Patea and Mangaehu catchments, respectively, with only some (natural) degree of riparian protection, or landowner fencing/planting that is not covered by a Council-prepared riparian plan. Within the catchment area, 46,908.9 ha (54%) is covered by Hill Country plans, addressing land management and sediment issues. This area is dominated by dry stock properties, as well as 6,588.7 ha (8%) of DOC owned land, and is located to the northeast and south east of the catchment.

1.3 Trends in lake water quality

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

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

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

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

The most recent lake water quality trend analysis, performed by the TRC for the 27 year period 1990-2017 (see Appendix II) has continued to support the findings and conclusions of Burns (2006), i.e. that the trophic level continues to increase at a very small, insignificant annual rate of change (0.01 $\pm$ 0.01 TLI units per year). Of the key variables (chlorophyll-a, secchi disc, total phosphorus and total nitrogen), only chlorophyll-a trended significantly, increasing slowly, within the mesotrophic level range and other variable showing significant temporal trends was nitrate which was also increasing.

1.4 Monitoring programme

1.4.1 Introduction

The Lake Rotorangi monitoring programme consists of two primary components.

1.4.2 Lake Rotorangi physicochemical sampling

In 2016-2017 and 2017-2018, 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 each year. Macroinvertebrate samples collected in the past from the lake bed at these two sites during the spring physicochemical survey were collected in 2017, as a triennial component of the programme. The aquatic macrophyte survey of the lake, last performed during autumn 2015, was repeated in autumn 2018.

1.5 Objective

The objective of this Report is to present the results of the 2016-2017 and 2017-2018 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 each year timed to coincide with:

a. pre-stratification period (spring) conditions (near 20 October);

b. stable summer stratification conditions (near 20 February);

c. pre-overturn (later summer) conditions (within one month of (b), and near 20 March); and

d. post-overturn winter conditions (near 20 June).

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

Table 1 Water quality parameters measured at the two sampling sites

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

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

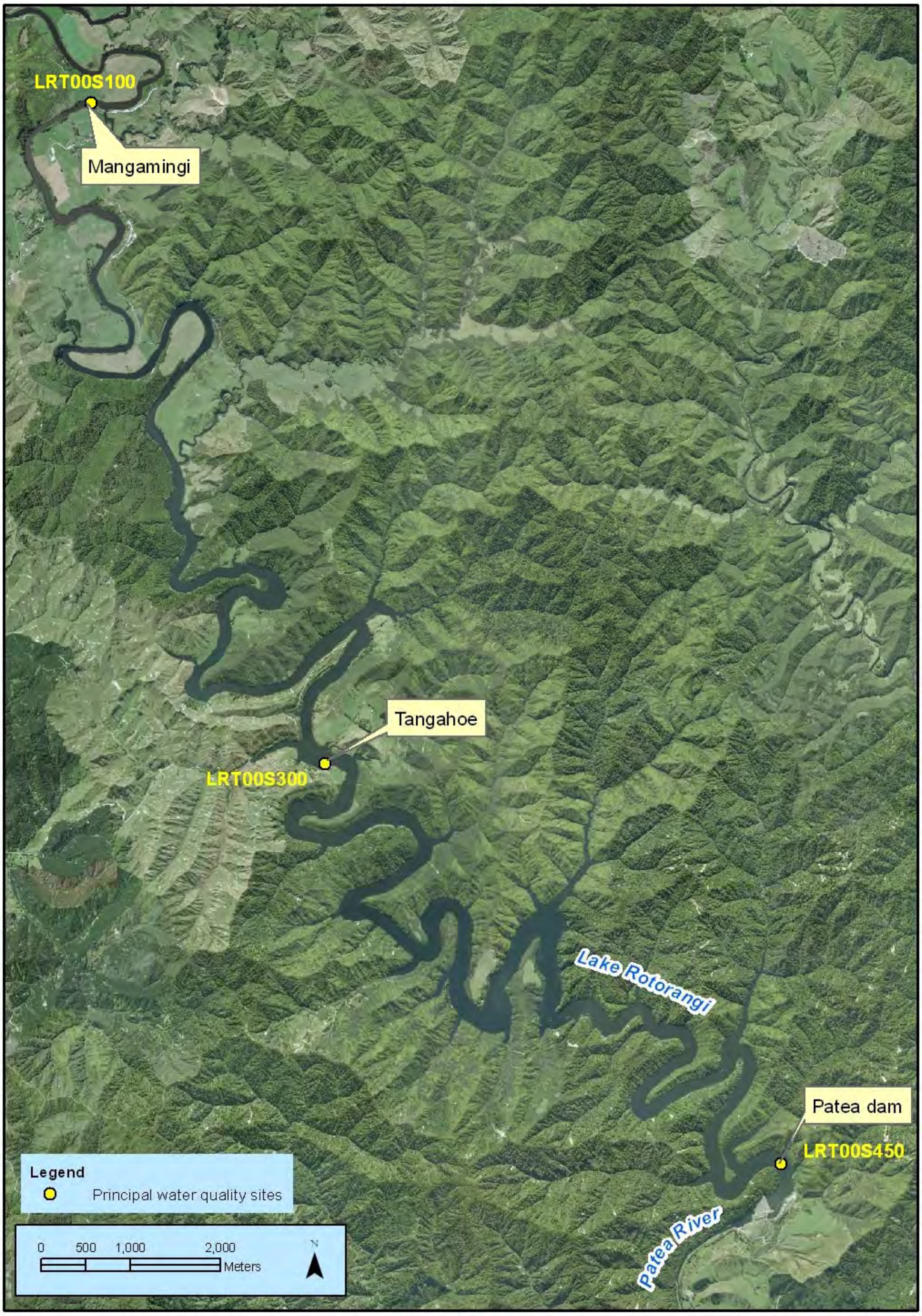


Figure 1 Aerial location map of Lake Rotorangi water quality sampling sites for 2016-2018 [LRT000300 and LRT000450]

In the years 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	Year	
		2016-2017	2017-2018
1	Spring	20 October 2016	18 October 2017
2	Late summer, stratification	20 February 2017	15 February 2018
3	Autumn, stratification	22 March 2017	19 March 2018
4	Winter	19 June 2017	21 June 2018

2016-2017

The spring sampling survey was performed under steady fresh recession river flow conditions following a wet period of nine small freshes in both catchments over the preceding month (see Figure 3 and Figure 4 and Appendix I). The late summer survey occurred under steady recession river flow conditions following a fresh two days earlier in the Mangaehu catchment, after a mainly dry period of two weeks. The autumn survey was performed under steady fresh recession flow conditions a week since a moderate fresh, preceded by a small fresh after a dry period of three weeks. The final (winter) survey was performed during relatively low river recession flow conditions seven and sixteen days after two small freshes, and after three moderate freshes in both catchments over the preceding six weeks. Lake level was moderate at the time of the spring (76.8 m asl), autumn (76.5 m asl) and winter (76.2 m asl) surveys, and high during the late summer (77.4 m asl) survey.

2017-2018

The spring sampling survey was performed under steady recession river flow conditions following two small river freshes in the preceding ten days and a large fresh in both catchments three weeks before (see Figure 6 and Figure 7 and Appendix I). The late summer survey occurred under steady recession flow conditions following three relatively small river freshes (one three days before) following a moderate fresh in both catchments two weeks before. The autumn survey was performed under steady recession flow conditions eight days since the largest flood of the monitoring period. The final (winter) survey was performed during flood recession flow conditions, three days after a large fresh, and after two small river freshes over the preceding month, following a wet two-week period with six freshes in both catchments. Lake level was moderate at the time of the spring (77.0 m asl) and late summer (76.4 m asl) surveys, high during the autumn (77.2 m asl) survey, and very high during the winter (77.8 m asl) survey.

Flow data for the Patea River, Mangaehu River and synthesised inflow to Lake Rotorangi are presented in Figure 2 to Figure 7 and attached as Appendix I. This synthetic flow is the flow entering the head of the lake (at Mangamingi) and equates to flows from the Patea River and Mangaehu River catchments above Mangamingi.

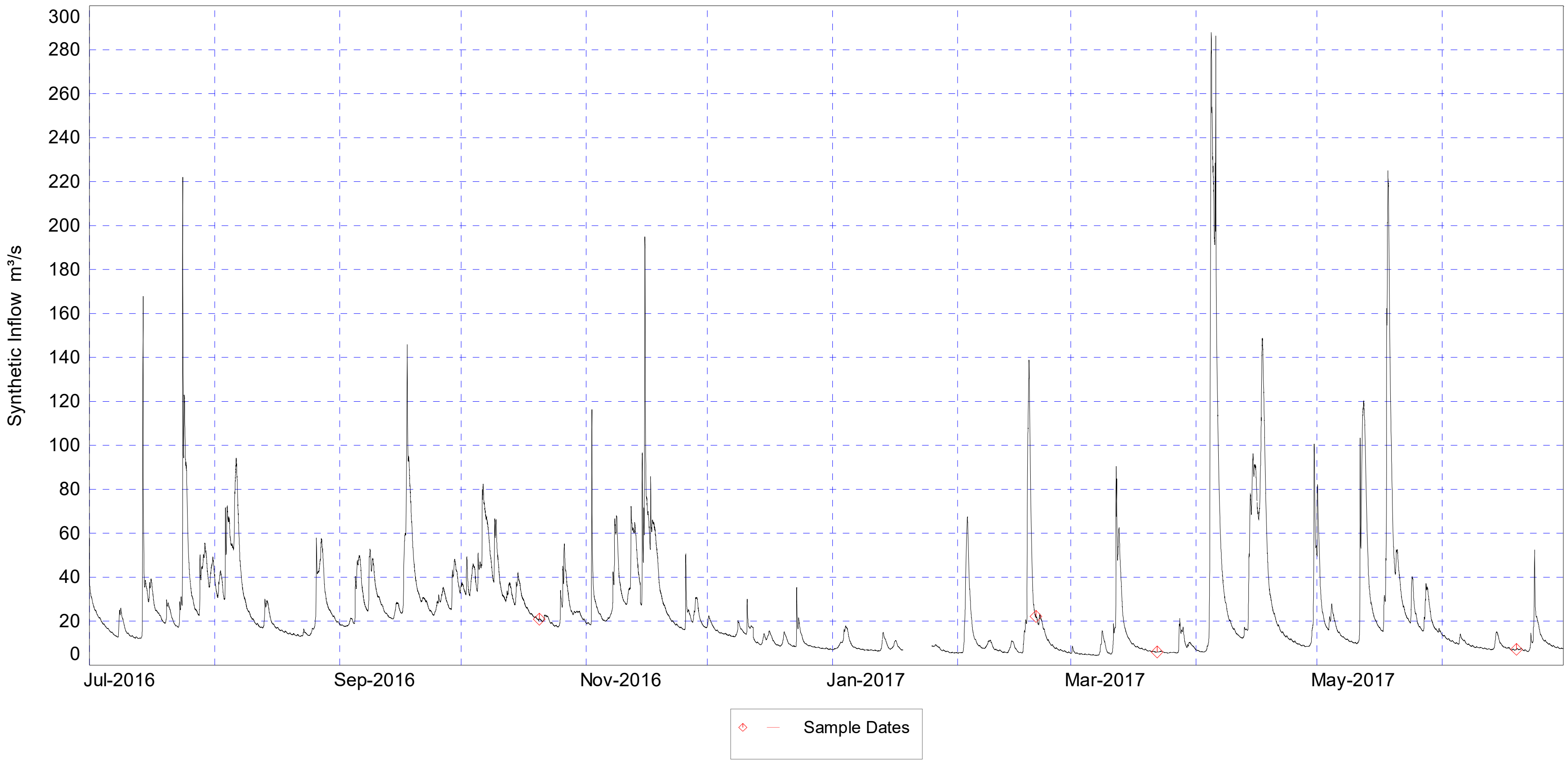


Figure 2 Synthetic inflow at Lake Rotorangi for the period 1 July 2016 to 30 June 2017

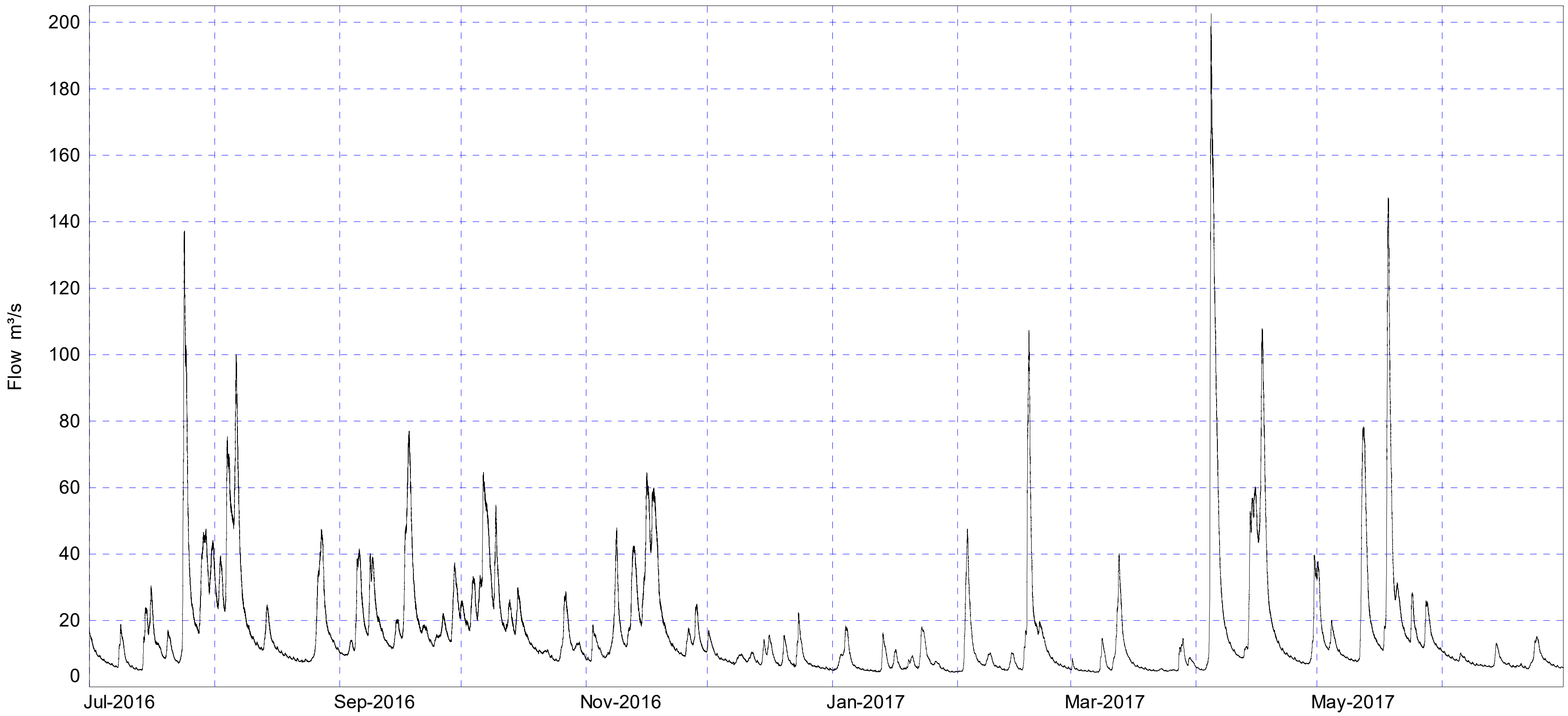


Figure 3 Flow in the Mangaehu River from July 2016 to June 2017

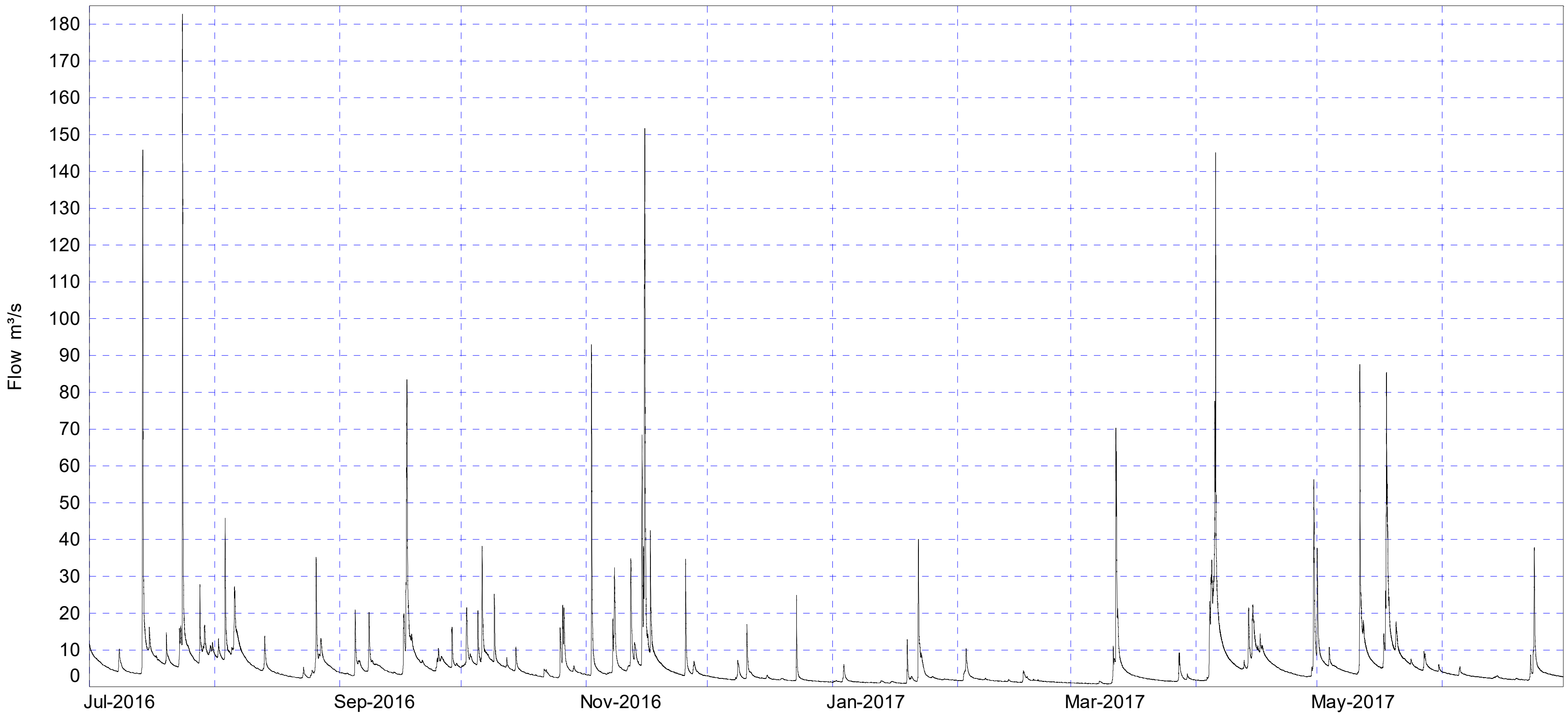


Figure 4 Flow in the Patea River at Skinner Road from July 2016 to June 2017

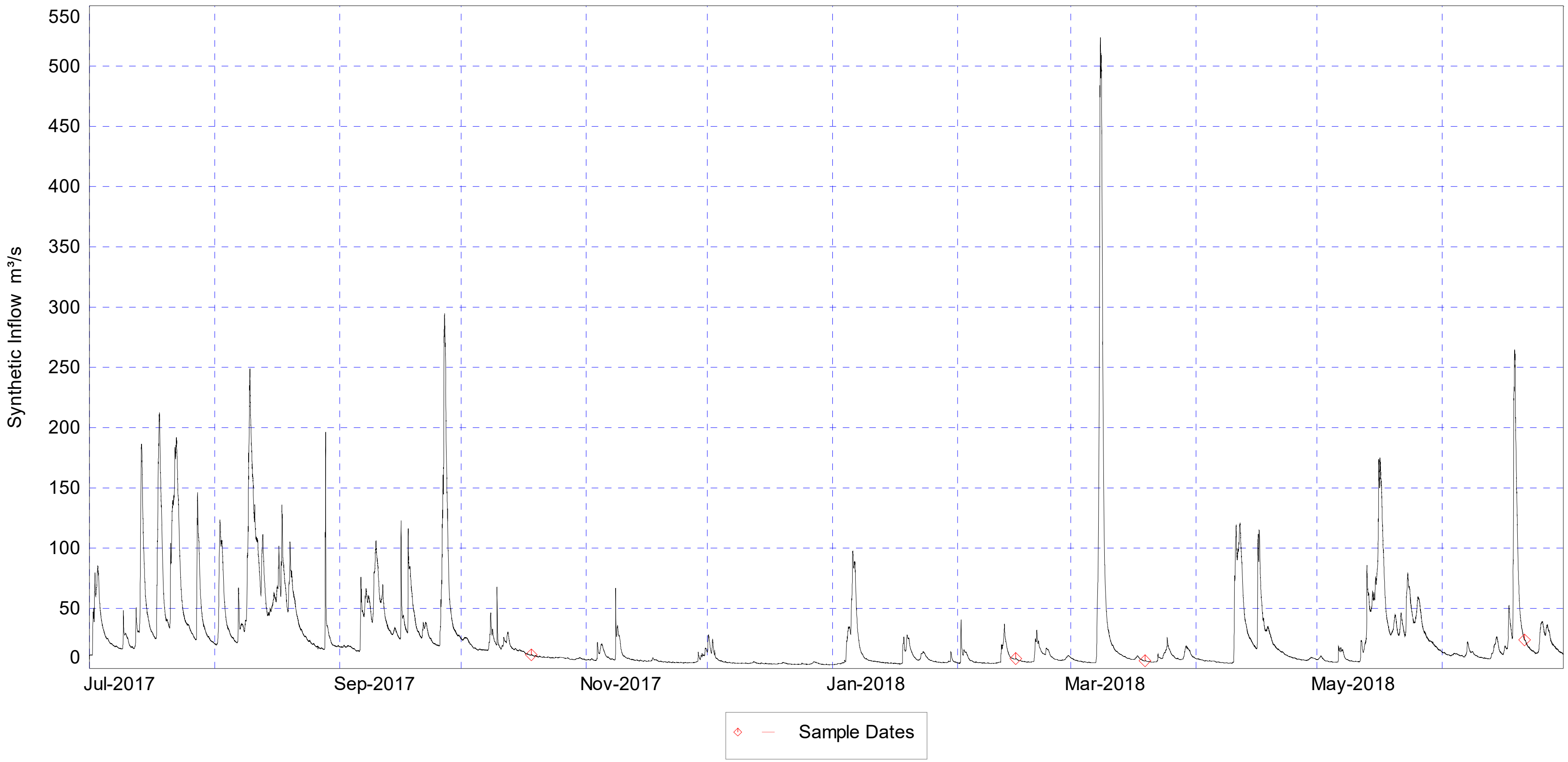


Figure 5 Synthetic inflow at Lake Rotorangi for the period 1 July 2017 to 30 June 2018

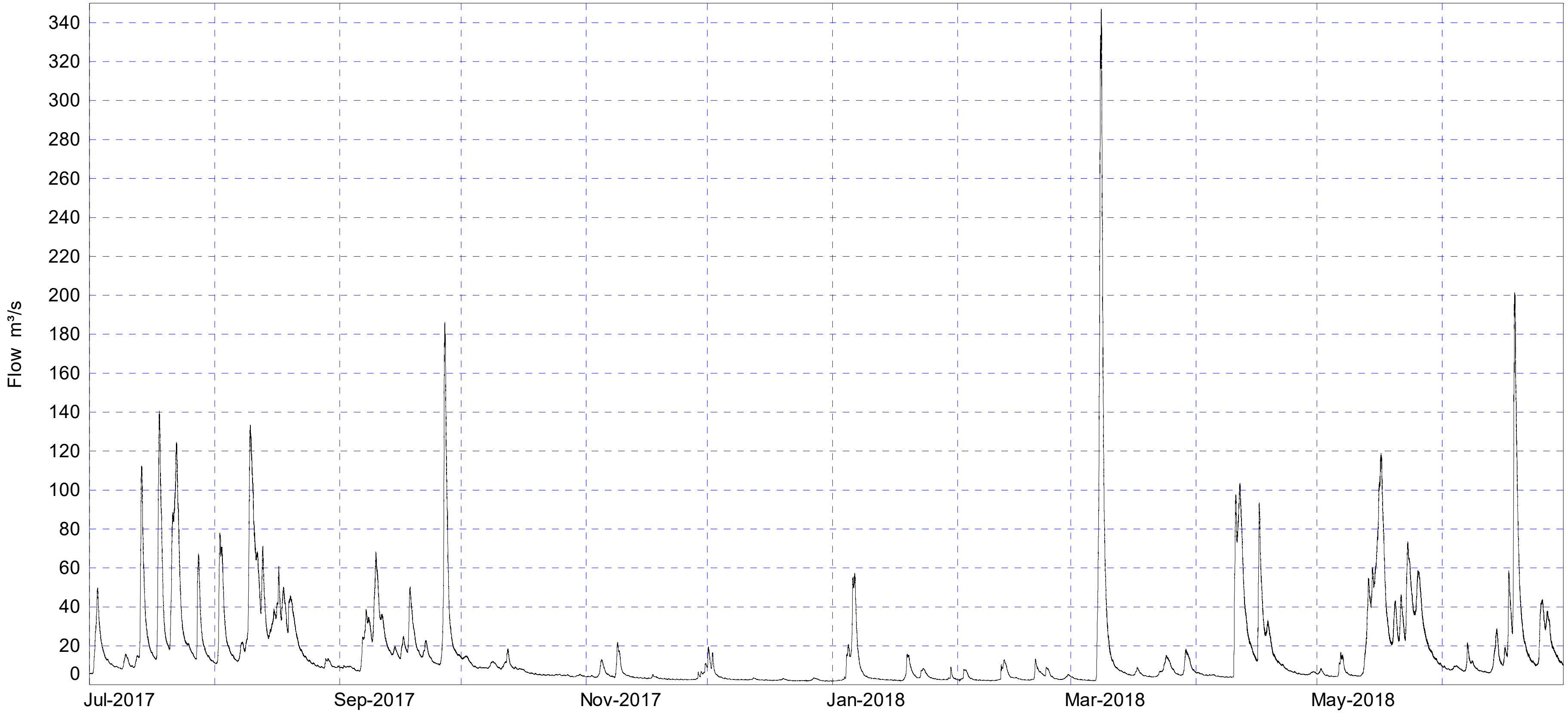


Figure 6 Flow in the Mangaehu River from July 2017 to June 2018

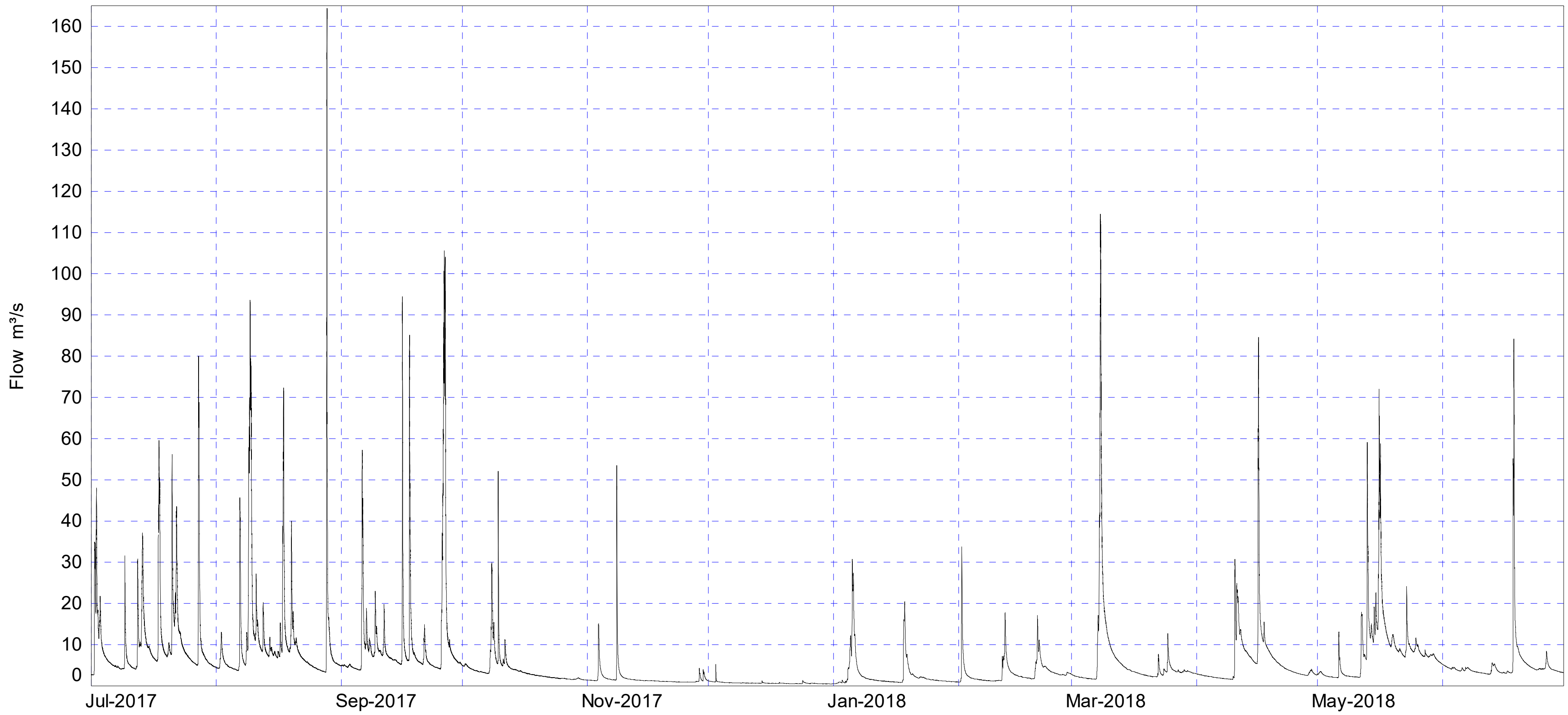


Figure 7 Flow in the Patea River at Skinner Road from July 2017 to June 2018

3 Results

3.1 General observations

Information recorded at each site on the four sampling occasions in 2016-2017 and in 2017-2018 is summarised in Table 3 and Table 4. 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 2016-2017

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	20.10.16	0920-1025	Overcast, fine	Moderate	15.4	15.5	Turbid, brown, surface ripple; no debris noted	1.48	0.94	39
	20.02.17	0935-1045	Overcast, fine	Calm	19.2	21.4	Clear, dark green; surface flat; no debris noted	2.96	1.82	39
	22.03.17	0810-0900	Overcast, drizzle	Calm	17.8	19.6	Clear, brown; surface flat; no debris noted	2.74	1.50	39
	19.06.17	0920-1015	Cloudy, foggy, recent rain	Calm	10.0	11.4	Turbid, brown; surface flat; no debris noted	1.90	1.45	38
L3	20.10.16	1105-1205	Overcast, fine	Moderate	16.3	16.3	Clear, green; surface ripple; no debris noted	2.06	1.43	52
	20.02.17	1125-1220	Overcast, fine	Calm	21.6	21.6	Clear, v. dark green; surface flat; no debris noted	4.06	2.89	52
	22.03.17	0940-1030	Overcast, rain	Calm	17.7	20.3	Clear brown; surface flat; no debris noted	3.01	1.86	52
	19.06.17	1100-1150	Sunny, fine after rain	Calm	12.9	11.5	Discoloured, green-brown; surface flat; no debris noted	2.10	1.89	51

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

Table 4 Observations at Lake Rotorangi monitoring sites on each sampling date during 2017-2018

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	18.10.17	0815-0940	Overcast, fine	Calm	14.7	14.7	Turbid, brown surface flat; no debris noted	2.03	1.24	40
	15.02.18	0830-0940	Fine, warm	Calm	19.8	23.6	Brown; surface flat; no debris noted	3.20	1.82	39
	19.03.18	0925-1020	Overcast, fine	Calm	16.9	18.8	discoloured, brown; surface flat; no debris noted	0.96	0.60	39
	21.06.18	0925-1050	Partial cloud, fine, after heavy rain	Calm	7.5	10.9	Turbid, brown; surface ripple; no debris noted	0.22	0.15	40
L3	18.10.17	1025-1115	Overcast, fine	Moderate -strong	16.7	15.0	Turbid, brown; surface sl. chop; no debris noted	1.74	1.17	53
	15.02.18	1020-1130	Fine after showers, warn	Moderate	24.9	24.6	No debris noted	4.50	2.90	52
	19.03.18	1100-1210	Partly cloudy, fine	Moderate	20.1	19.4	Turbid, green; surface flat; no debris noted	2.56	1.76	53
	21.06.18	1140-1250	Partial cloud, fine after heavy rain	Light	10.0	10.9	Turbid, brown; surface rippled; no debris noted	1.34	0.92	53

[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 5.

Table 5 Statistical summary of surface water temperature data from June 1990 to June 2016

Location	Parameter	Unit	Minimum	Maximum	Median	N
L2 surface	Temperature	°C	9.2	23.9	17.2	102
L3 surface	Temperature	°C	9.5	24.6	17.7	103

The two lake sites (L2 and L3) continued to exhibit varying degrees of thermal stratification during the monitoring period (Figure 8 and Figure 9) typical of the majority of past years' stratification patterns. Temperatures measured in the surface and bottom waters at each lake site, during the 2016-2017 and 2017-2018 periods, are compared with the averages of all data for similar months prior to each year's sampling surveys in Table 6.

Table 6 Temporal changes in temperature (˚C) of surface and bottom waters at each Lake Rotorangi site (October 2016 to June 2018)

Sites	L2		L3	
Date	Surface	Bottom	Surface	Bottom
October 2016	15.5 (14.7)	8.8 (8.9)	16.3 (14.9)	8.5 (8.7)
February 2017	21.4 (21.8)	9.1 (9.6)	21.6 (22.1)	8.8 (9.4)
March 2017	19.6 (19.4)	9.2 (9.8)	20.3 (19.8)	8.8 (9.6)
June 2017	11.4 (11.2)	9.8 (9.4)	11.5 (11.3)	9.1 (9.5)
October 2017	14.7 (14.7)	9.3 (8.9)	15.0 (14.9)	8.8 (8.7)
February 2018	23.8 (21.8)	9.7 (9.6)	24.6 (22.1)	9.1 (9.4)
March 2018	19.0 (19.5)	10.5 (9.8)	19.4 (19.8)	9.7 (9.6)
June 2018	11.1 (11.2)	11.2 (9.4)	10.9 (11.3)	9.9 (9.5)

Note: ( ) = average monthly temperature for period 1984 to mid-2016/7

In 2016-2017, all surface water temperatures at both sites were within past ranges measured at these sites (Table 5). Temperatures were within 0.2˚C to 0.8˚C of past monthly average temperatures at site L2 and 0.2˚C to 1.4˚C at site L3, at the time of all surveys. Bottom water temperatures at both sites were lower than surface water temperatures by 1.4˚C to 1.6˚C (winter) and 12.3 to 12.8˚C (late summer) but within 0.1˚C to 0.6˚C of corresponding monthly average temperatures throughout most of the year. These two sites' bottom water temperatures (8.8˚C to 9.8˚C and 8.5˚C to 9.1˚C) showed a narrow range (1.0°C [L2] and 0.6˚C [L3]), due to minimal mixing through most of the year, while their surface water temperature ranges were much wider (10.0˚C [L2] to 10.1˚C [L3]).

In 2017-2018, all surface water temperatures at both sites again were within past ranges measured at these sites (Table 5), though the late summer values were within 0.1˚C to 0.2˚C of the highest recorded, in February 1994 at similar times of day. Temperatures were within 0.1˚C to 2.0˚C of past monthly average temperatures at site L2 and 0.7˚C to 2.5˚C at site L3, at the time of all surveys. Bottom water temperatures at both sites were similar to surface water temperatures in winter, and were lower than surface water temperatures by 14.1 to 15.5˚C in late summer, but within 0.0˚C to 0.4˚C of corresponding monthly average temperatures throughout most of the year. These two sites' bottom water temperatures (9.3°C to 11.2˚C and 8.8°C to 9.9˚C) showed a narrow range, due to minimal mixing through most of the year, with the exception of post flooding in March and June 2018 when bottom water temperature at site L2 (10.5°C and 11.2°C) rose after mixing. Surface water temperature ranges were much wider (12.7°C [L2] to 13.7°C [L3]).

Water temperature and dissolved oxygen profiles at each site are illustrated in Figure 8 and Figure 9 for the four sampling occasions in each of the 2016-2017 and 2017-2018 periods.

In 2016-2017, partial thermal stratification was recorded at sites L2 and L3 at the time of the October 2016 survey (Figure 8) while both summer-autumn surveys illustrated more well-established thermal stratification at these mid and lower lake sites. The location of the thermocline during summer-autumn was between 9 and 12 m below the lake surface at site L2, and 7 to 9 metres at site L3. The occurrence of several significant freshes between early April and the winter June 2017 survey, and cooling of epilimnetic waters, contributed to almost complete destruction of temperature stratification at these sites by the time of the June 2017 survey, although strong dissolved oxygen stratification remained at site L3 at this time (see section 3.1.2), a similar situation to that monitored in many previous years.

In 2017-2018, again partial thermal stratification was recorded at sites L2 and L3 at the time of the October 2017 survey (Figure 9), while both summer-autumn surveys illustrated more well-established thermal stratification at these mid and lower lake sites. The location of the thermocline at both sites during late summer survey was between 6 and 7 m below the lake surface at both sites, and during early autumn was between 22 and 24 metres. The occurrence of several significant freshes between mid-May and the winter June 2018 survey, and cooling of epilimnetic waters, contributed to almost complete destruction of temperature stratification at these sites by the time of the June 2018 survey, although some dissolved oxygen stratification remained at site L3 at this time (see section 3.1.2), a similar situation to that monitored in many previous years.

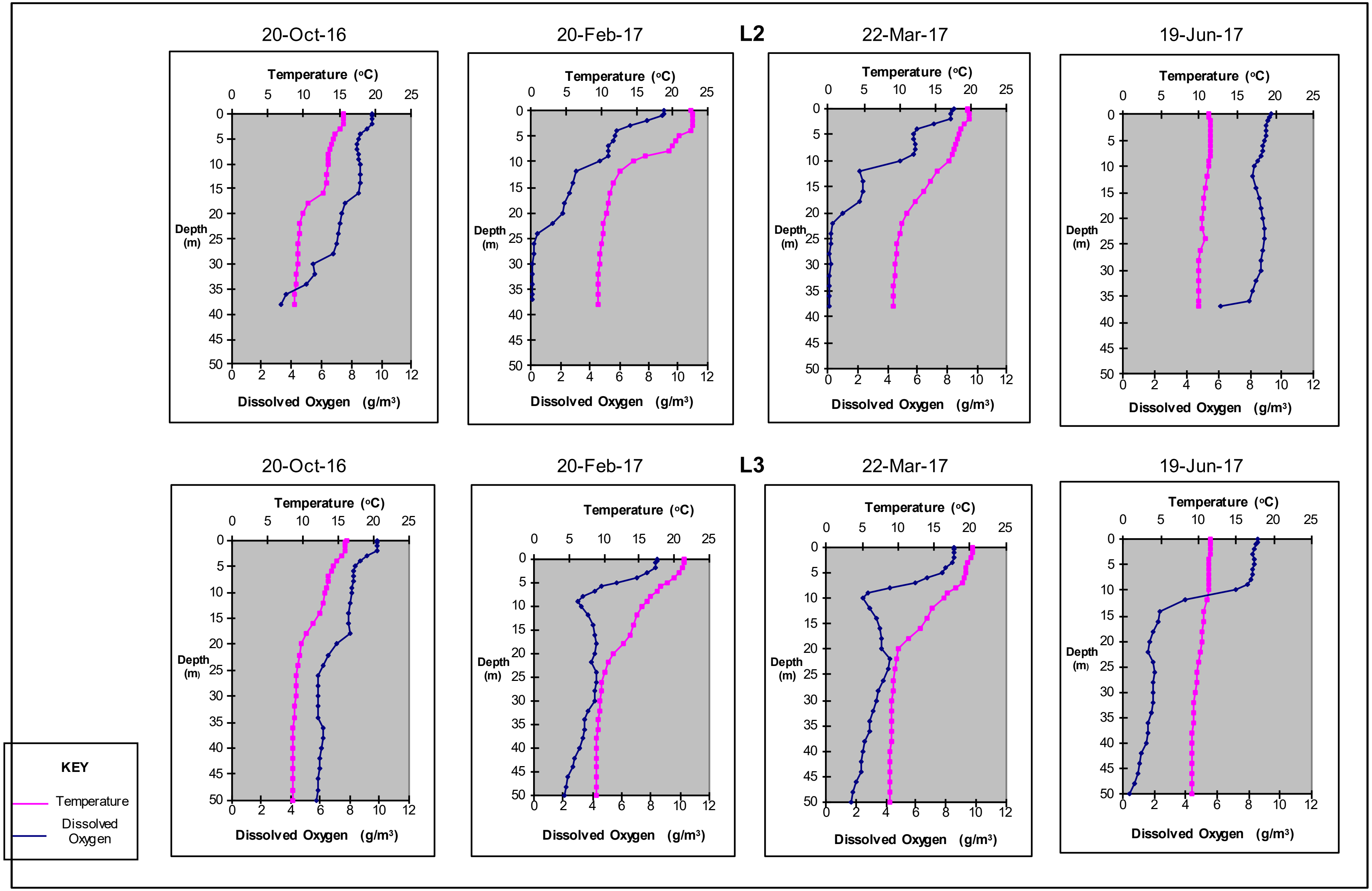


Figure 8 Temperature (°C) and dissolved oxygen (g/m³) profiles for sites L2 and L3, 2016-2017

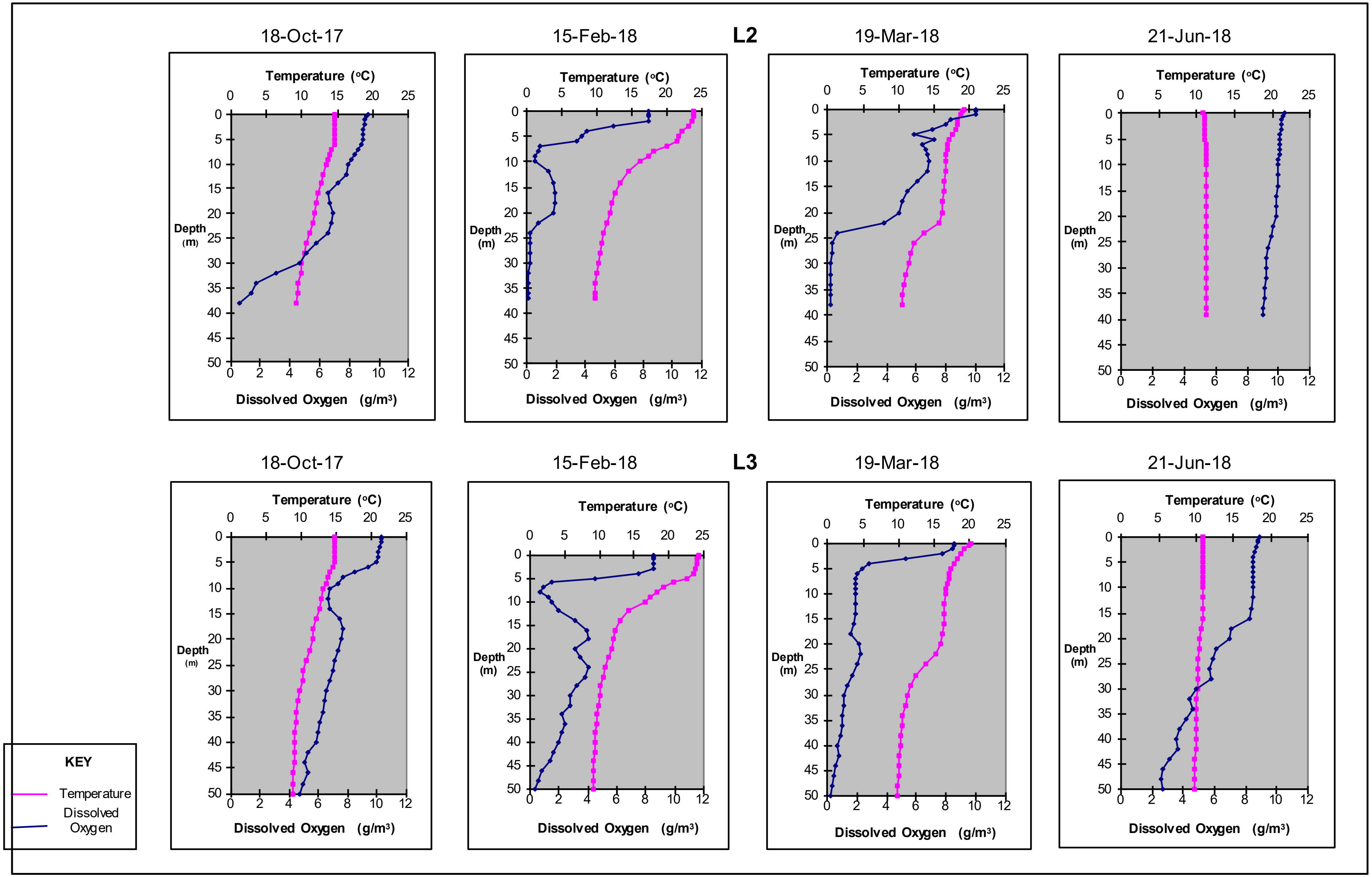


Figure 9 Temperature (°C) and dissolved oxygen (g/m^3) profiles for sites L2 and L3, 2017-2018

3.1.2 Dissolved oxygen stratification

A summary of historical dissolved oxygen data is provided in Table 7.

Table 7 Statistical summary of dissolved oxygen data from June 1990 to June 2016

Location	Parameter	Unit	Minimum	Maximum	Median	N
L2 surface	Dissolved oxygen	g/m^3	6.8	11.1	8.8	102
	Dissolved oxygen saturation	%	68	116	91	102
L3 surface	Dissolved oxygen	g/m^3	3.6	11.0	8.8	103
	Dissolved oxygen saturation	%	34	116	95	103

Table 8 Temporal changes in percentage dissolved oxygen saturation in surface and bottom waters at each Lake Rotorangi site (October 2016 to June 2018)

Sites	L2		L3	
Date	Surface	Bottom	Surface	Bottom
October 2016	96 (94)	29 (29)	102 (97)	49 (33)
February 2017	102 (98)	1 (2)	94 (101)	18 (7)
March 2017	94 (92)	1 (4)	96 (93)	15 (7)
June 2017	84 (81)	54 (56)	79 (65)	3 (13)
October 2017	91 (94)	5 (28)	102 (97)	38 (34)
February 2018	99 (99)	1 (2)	103 (101)	3 (8)
March 2018	108 (92)	2 (4)	94 (93)	2 (7)
June 2018	94 (82)	83 (56)	81 (65)	38 (13)

Note: ( ) = average monthly saturation for period 1984 to mid-2016/17

2016-2017

Surface water percentage dissolved oxygen saturation levels were within past ranges at both sites during the 2016-2017 monitoring year (Table 7). Levels varied in relation to average saturation levels recorded from previous monitoring surveys for the four relevant months. Surface levels were within 16% of total saturation or supersaturated with the exception of the winter, partial overturn level which fell to 79% saturation at site L3. The level was also at slightly below the saturation normally found at the time of the summer survey at site L3. Partial mixing of relatively highly saturated surface waters with the poorer quality hypolimnetic waters was recorded at site L3 by the mid-winter monitoring in June 2017, as indicated by the decrease in percentage saturation to well below 100% saturation.

Bottom water percentage 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 8) in the hypolimnetic lake waters during the survey period, but to a somewhat lesser degree at the time of the spring survey at both sites, and to a small degree at the time of the winter survey at site L2.

Total dissolved oxygen depletion was recorded within the hypolimnion during the February and March 2017 surveys at the mid lake site (L2), while the lower lake site L3 did not record total depletion within the hypolimnion at these times but showed near total depletion below 45 metres in winter, as has occurred from time to time in the past (see TRC, 2008). Some depletion was found at both sites in spring, more particularly below depths of 30 metres. During the late summer-autumn period, anoxic conditions (i.e. dissolved oxygen concentrations less than 0.5 g/m^3) were recorded at depths below 25 m at site L2, but not at site L3.

Significant dissolved oxygen stratification remained at site L3 at the time of the winter survey, despite minimal thermal stratification, a similar situation to that recorded at site L3 in twenty-one of the previous twenty-three years. Dissolved oxygen levels were at or 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 45 m in depth (Figure 8). There was little oxygen depletion at site L2 in winter, indicative of complete lake mixing, with levels of more than 8 g/m^3 recorded throughout all but the lower 2 metres of the lake's depth of 39 metres.

2017-2018

Surface water percentage dissolved oxygen saturation levels were within past ranges at both sites during the 2017-2018 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 9% of total saturation or supersaturated with the exception of the winter, partial overturn level which fell to 81% saturation at site L3. The level was slightly above the saturation normally found at the time of the autumn survey at site L2. Partial mixing of relatively highly saturated surface waters with the poorer quality hypolimnetic waters was recorded at site L3 by the mid-winter monitoring in June 2018, as indicated by the decrease in percentage saturation to well below 100% saturation.

Bottom water saturation levels varied according to the degree of stratification established in the lake at the time of sampling. The deeper mid and lower lake sampling sites (L2 and L3) displayed lengthy periods of significant dissolved oxygen reduction (Figure 9) in the hypolimnetic lake waters during the survey period, but to a somewhat lesser degree at the time of the spring and winter surveys at site L3 and to only a small degree at the time of the winter survey at site L2.

Total dissolved oxygen depletion was recorded within the hypolimnion during the February and March 2018 surveys at the mid lake site (L2), while the lower lake site L3 did not record total depletion within the hypolimnion at these times, nor 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 a depth of 30 metres at site L2. During the late summer-autumn period, anoxic conditions (i.e. dissolved oxygen concentrations less than 0.5 g/m^3) were recorded at depths below 25 m at site L2, but not at site L3.

Significant dissolved oxygen stratification remained at site L3 at the time of the winter survey, despite minimal thermal stratification, a similar situation to that recorded at site L3 in twenty-two of the previous twenty-four 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 and autumn surveys beyond 40 m to 45 m in depth (Figure 9). There was little oxygen depletion at site L2 in winter, indicative of complete lake mixing, with levels of more than 9 g/m^3 recorded through the lake's depth of 40 metres.

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

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

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

Burns (2006) noted that VHOD rates had been very variable over the 1990-2006 period due to vertical turbulence (provided by wide ranges of inflows) in this reservoir-type lake system and therefore were unlikely to provide useful trend information (see Figures in Appendix II).

3.1.3 Secchi disc transparency/suspended solids

A summary of historical data is provided in Table 9.

Table 9 Statistical summary of physical water quality data from 1990 to June 2016

Location	Parameter	Unit	Minimum	Maximum	Median	N
L2 Surface	Secchi disc transparency	m	0.09	5.23	2.78	102
	Black disc transparency	m	0.09	4.50	2.20	95
	Turbidity	NTU	0.4	240	1.6	88
	Suspended solids	g/m^3	<2	170	2	95
	Conductivity @ 20°C	g/m^3	5.4	15.0	11.0	82
L2 Epilimnion	Turbidity	mS/m	0.6	250	1.8	93
	Suspended solids	g/m^3	<2	180	2	100
	Conductivity @ 20°C	mS/m	5.3	14.5	11.1	97
L2 Hypolimnion	Turbidity	NTU	1.6	510	5.4	95
	Suspended solids	g/m^3	<2	340	3	101
	Conductivity @ 20°C	mS/m	5.8	13.5	10.7	99
L3 Surface	Secchi disc transparency	m	0.12	7.0	3.2	103
	Black disc transparency	m	0.12	5.25	2.7	90
	Turbidity	NTU	0.4	250	1.3	91
	Suspended solids	g/m^3	<2	170	<2	97
	Conductivity @ 20°C	mS/m	6.2	15.2	10.6	86
L3 Epilimnion	Turbidity	NTU	0.4	250	1.5	93
	Suspended solids	g/m^3	<2	170	2	101
	Conductivity @ 20°C	mS/m	6.2	15.0	10.6	97
L3 Hypolimnion	Turbidity	NTU	0.7	780	3.2	95
	Suspended solids	g/m^3	<2	500	<2	103
	Conductivity @ 20°C	mS/m	6.2	12.4	10.3	99

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

Data recorded from both sites during the 2016-2017 year (Table 10) were within ranges of previous results, with the secchi disc transparency range at both sites being the narrowest recorded, around median values, and suspended solids and turbidities ranges also relatively narrow.

In 2017-2018, data recorded from both sites were within the ranges of previous results, with secchi disc transparency much lower than median value in autumn and winter at site L2, and suspended solids and turbidity levels correspondingly high, due to the proximity of freshes.

Table 10 Physical water quality monitoring data for the two Lake Rotorangi sites in the 2016-2017 period

	Sites		L2			L3		
Date	Parameter	Unit	S	E	H	S	E	H
20.10.16	Secchi disc	m	1.48	-	-	2.06	-	-
	Turbidity	NTU	5.0	8.5	5.5	2.1	7.6	3.4
	Suspended solids	g/m³	2	5	3	<2	2	<2
	Conductivity @ 20°C	mS/m	9.8	9.9	10.3	9.2	9.0	9.5
20.02.17	Secchi disc	m	2.96	-	-	4.08	-	-
	Turbidity	NTU	1.4	5.0	2.5	0.8	1.1	1.5
	Suspended solids	g/m³	<2	3	<2	<2	<2	<2
	Conductivity @ 20°C	mS/m	10.0	11.2	10.2	11.5	11.5	9.3
22.03.17	Secchi disc	m	2.74	-	-	3.01	-	-
	Turbidity	NTU	1.2	2.0	2.3	0.9	1.0	1.0
	Suspended solids	g/m³	<2	<2	<2	<2	<2	<2
	Conductivity @ 20°C	mS/m	11.1	10.8	9.0	9.8	9.7	9.2
19.06.17	Secchi disc	m	1.90	-	-	2.10	-	-
	Turbidity	NTU	4.1	4.1	4.0	3.6	3.6	2.1
	Suspended solids	g/m³	<2	<2	<2	<2	<2	<2
	Conductivity @ 20°C	mS/m	9.4	9.4	11.6	9.2	9.2	9.3
Range	Secchi disc	m	1.48-2.96	-	-	2.06-4.08	-	-
	Turbidity	NTU	1.2-5.0	2.0-8.5	2.3-5.5	0.8-3.6	1.0-7.6	1.0-3.4
	Suspended solids	g/m³	<2-2	<2-5	<2-3	<2	<2-2	<2
	Conductivity @ 20°C	mS/m	9.4-11.1	9.4-11.2	9.0-11.6	9.2-11.5	9.0-11.5	9.2-9.5

Note: [Sites: S = surface; E = epilimnion; H = hypolimnion; ( ) = limited data] low conductivities, yet low turbidities

Table 11 Physical water quality monitoring data for the two Lake Rotorangi sites in the 2017-2018 period

	Sites		L2			L3		
Date	Parameter	Unit	S	E	H	S	E	H
18.10.17	Secchi disc	m	2.03	-	-	1.74	-	-
	Turbidity	NTU	2.8	3.1	14	3.2	3.4	3.8
	Suspended solids	g/m³	5	3	9	4	3	2
	Conductivity @ 20°C	mS/m	10.0	10.0	6.9	8.2	8.4	9.8
15.02.18	Secchi disc	m	3.20	-	-	4.50	-	-
	Turbidity	NTU	1.2	1.8	2.7	1.1	1.1	2.1
	Suspended solids	g/m³	<2	<2	<2	<2	<2	<2
	Conductivity @ 20°C	mS/m	12.1	12.2	9.4	12.6	12.6	9.4
19.03.18	Secchi disc	m	0.96	-	-	2.56	-	-
	Turbidity	NTU	7.4	9.8	16	1.5	2.3	5.7

	Sites		L2			L3		
Date	Parameter	Unit	S	E	H	S	E	H
	Suspended solids	g/m^3	7	6	16	<2	2	5
	Conductivity @ 20°C	mS/m	9.4	9.3	10.7	11.6	11.6	10.7
21.06.18	Secchi disc	m	0.22	-	-	1.34	-	
	Turbidity	NTU	56	59	67	5.3	5.4	8.6
	Suspended solids	g/m^3	50	51	57	3	3	6
	Conductivity @ 20°C	mS/m	9.0	9.0	8.7	9.8	9.9	10.8
Range	Secchi disc	m	0.22-3.20	-	-	1.34-4.50	-	-
	Turbidity	NTU	1.2-56	1.8-59	2.7-67	1.1-5.3	1.1-5.4	2.1-8.6
	Suspended solids	g/m^3	<2-50	<2-51	<2-57	<2-4	<2-3	<2-6
	Conductivity @ 20°C	mS/m	9.0-12.1	9.0-12.2	6.9-10.7	8.2-12.6	8.4-12.6	9.4-10.8

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

2016-2017

The impacts of relatively recent significant freshes resulted in poor secchi disc clarity at sites L2 and L3 surface waters in spring with elevated turbidity and suspended solids levels. In the hypolimnion, turbidity and suspended solids levels at or below median values occurred at both sites throughout the year.

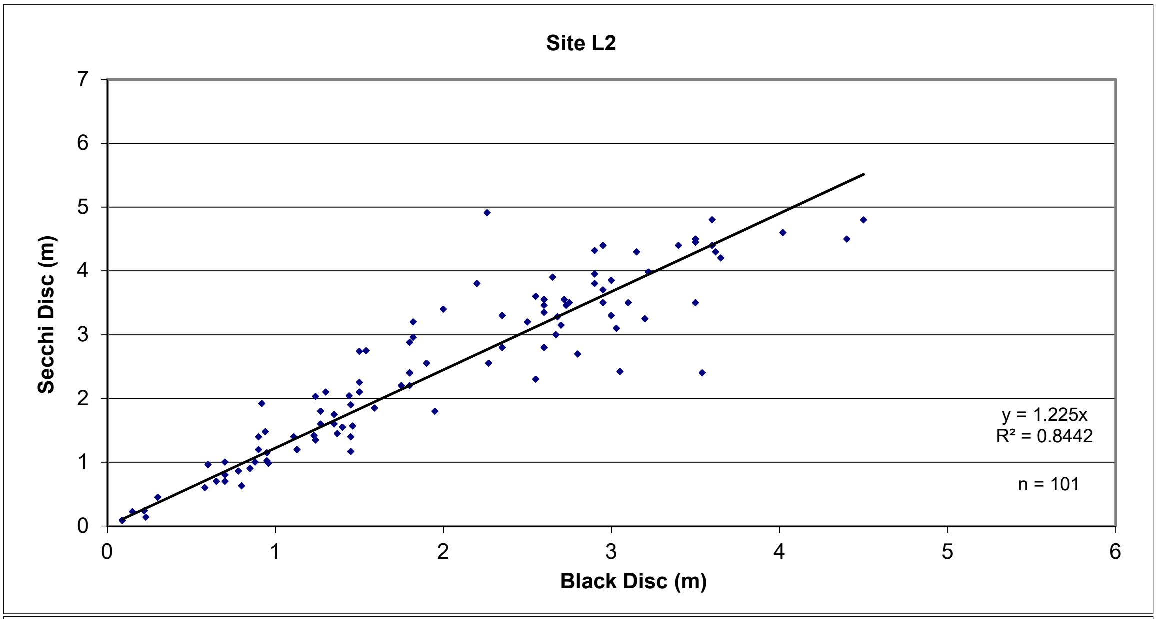
A narrower range of secchi disc transparency levels was recorded at site L2 (1.48 to 2.96 m) and site L3 (2.06 to 4.08 m) during the monitoring year. Impacts of river freshes upon lake clarity through the water column at site L2 were more marked in October 2016 due to several freshes preceding this survey.

2017-2018

The impacts of recent significant freshes resulted in very poor secchi disc clarity at site L2 surface waters in autumn and winter with elevated turbidity and suspended solids levels throughout the water column in winter.

A lower range of secchi disc transparency levels was recorded at site L2 (0.22 to 3.20 m) than site L3 (1.34 to 4.50 m) during the monitoring year. Impacts of river freshes upon lake clarity through the water column at site L2 were more marked in April and June 2016 due to several freshes preceding these surveys.

Black disc transparency readings (Table 3) provide an estimate of horizontal water clarity, which is of value in the optical characterisation of water, and in relation to human recreational water use. Black disc observations in conjunction with vertical (secchi disc) readings provide information on the penetration of diffuse light into water. Pairs of observations will continue to be measured in Lake Rotorangi to provide a suitable database from which interpretations can be made at a later date. A correlation between secchi disc and black disc transparencies has been prepared for both of the sampling sites (Figure 10). 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.



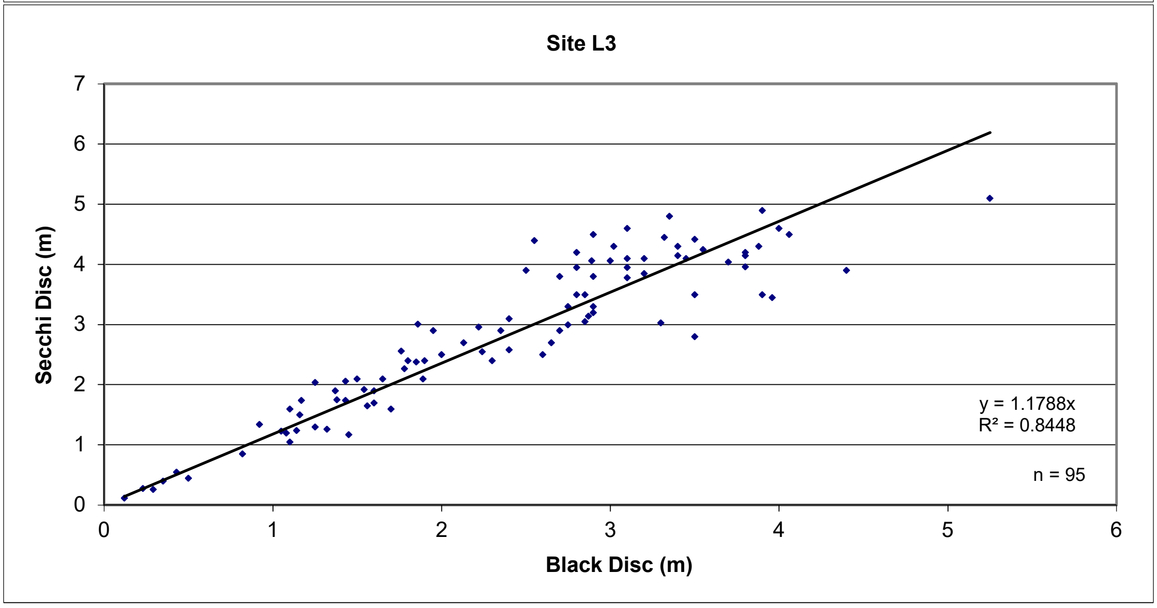


Figure 10 Relationship between secchi and black disc transparency at each sampling site

These trends have continued to be recorded during the most recent monitoring period under a moderate range of clarities.

3.1.4 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 12.

Table 12 Statistical summary of chlorophyll-a data from 1990 to June 2016

Location	Parameter	Unit	Minimum	Maximum	Median	Mean	N
L2 photic zone	Chlorophyll-a	mg/m^3	<1.0	13.9	2.6	3.1	101
L3 photic zone	Chlorophyll-a	mg/m^3	<1.0	13.4	2.2	3.2	101

Results recorded during the monitoring programme are presented in Table 13 and a summary of yearly results in Table 14. The detection limit in June 2018 was higher than previously as the result of change in laboratory performing the (same) analysis.

Table 13 Chlorophyll-a concentrations (mg/m^3) (including historical monthly means) for the Lake Rotorangi sites

Date	Sites					
	L2			L3		
	Mean (1984-2016)	Result 2016-17	Result 2017-18	Mean (1984-2016)	Result 2016-17	Result 2017-18
October	3.5	4.4	2.5	3.9	4.6	13.0
February	3.6	4.9	5.1	3.1	1.7	5.4
March	3.8	4.2	10.7	4.4	5.1	3.9
June	1.7	3.8	<5	1.5	1.7	<3
Annual Range: 2016-2018	-	3.8-4.9	2.5-10.7	-	1.7-5.1	<3-13.0
Historical Range: 1984-2016	-	<1-13.9		-	<1-15	

Table 14 Summary of past chlorophyll-a concentrations (mg/m3) survey data for the two Lake Rotorangi sites (1984 to 2017, calendar)

	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	3.1	<1-4.0	4	5.2	1.1-10.0
2015	3	3.8	<1-5.5	3	4.5	<1-8.2
2016	4	4.2	1.7-5.0	4	3.4	1.7-4.6
2017	4	3.8	2.5-4.9	4	5.7	1.7-13.0

All chlorophyll-a concentrations measured at the two sites over the 2016-2017 and 2017-2018 periods were within past ranges (Table 12) found by surveys since 1990.

2016-2017

In 2016-2017, concentrations at site L2 had the narrowest annual range on record, with all values higher than the historical seasonal mean values. Concentrations at site L3 were higher than the historical median value on all but the late summer survey.

Maximum lake chlorophyll-a concentrations have tended to be measured during late summer or autumn at sites L2 and L3. Over the 2016-2017 period, the highest concentrations were found in the photic zone of the mid lake in summer and in the lower lake in autumn. All measured concentrations were within previous ranges recorded since 1984 at both sites (Table 13 and Table 14). The maximum chlorophyll-a concentration of 5.1 mg/m^3 was measured at lake site L3 during the autumn period but this was only 0.2 mg/m^3 higher than the concentration found at site L2 in late summer.

Mean 2016 values at both sites were within historical values for the sampling period from 1984 to 2015 where the average annual means have been 3.1 mg/m^3 for site L2 (range: 1.2 to 5.3 mg/m^3) and 3.1 mg/m^3 for site L3 (range: 1.3 to 5.3 mg/m^3).

2017-2018

In 2017-2018, concentrations at both sites varied more widely than usual, though comparison with previous historical seasonal means is limited without definite values for winter. Concentrations at site L2 varied from less than the seasonal mean in spring to greater than the seasonal mean in autumn, whereas at site L2 concentrations varied conversely, being higher in spring and lower in autumn.

While maximum lake chlorophyll-a concentrations have tended to be measured during late summer or autumn at sites L2 and L3, in 2017-2018 the highest concentration in the photic zone of the lower lake was recorded in spring. All measured concentrations were within previous ranges recorded since 1984 at both sites (Table 13 and Table 14). The maximum chlorophyll-a concentration of 13.0 mg/m^3 was measured at lake site L3 during the spring period and this was 2.3 mg/m^3 higher than the concentration found at site L2 in autumn.

Mean 2017 values were within historical values at site L2 but 0.4 higher at site L3 for the sampling period from 1984 to 2016. The average annual means to July 2016 have been 3.1 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).

3.1.4.1 Nutrients

A summary of historical nutrients data is provided in Table 15, with water quality data relating to nutrient species, measured during the monitoring period, summarised for each site in Table 16 to Table 19. The results are discussed in relation to the epilimnion and hypolimnion of the lake.

Table 15 Statistical summary of nutrients data from 1990 to June 2016

Site	Parameter	Unit	Minimum	Maximum	Median	No. of samples
L2 Epilimnion	Dissolved reactive phosphorus	g/m^3P	<0.003	0.018	0.005	101
	Total phosphorus	g/m^3P	0.006	0.27	0.023	101
	Ammonia nitrogen	g/m^3N	<0.003	0.37	0.019	101
	Nitrite	g/m^3N	<0.001	0.018	0.007	91
	Nitrate	g/m^3N	<0.01	0.99	0.31	93
	Total Kjeldahl nitrogen	g/m^3N	<0.01	1.20	0.26	98
	Total nitrogen	g/m^3N	0.20	1.65	0.62	97
	pH		6.8	8.6	7.5	93
L2 Hypolimnion	Dissolved reactive phosphorus	g/m^3P	<0.003	0.029	0.008	101
	Total phosphorus	g/m^3P	0.008	0.46	0.022	101
	Ammonia nitrogen	g/m^3N	0.003	0.44	0.075	101
	Nitrite	g/m^3N	<0.001	0.022	0.008	91
	Nitrate	g/m^3N	0.02	0.93	0.50	95
	Total Kjeldahl nitrogen	g/m^3N	<0.01	0.99	0.28	99
	Total nitrogen	g/m^3N	0.45	1.72	0.78	99
	pH		6.5	7.4	6.9	94
L3 Epilimnion	Dissolved reactive phosphorus	g/m^3P	<0.003	0.023	0.004	101
	Total phosphorus	g/m^3P	0.004	0.33	0.018	101
	Ammonia nitrogen	g/m^3N	<0.003	0.183	0.011	101
	Nitrite	g/m^3N	<0.001	0.020	0.005	91
	Nitrate	g/m^3N	<0.01	0.83	0.35	93
	Total Kjeldahl nitrogen	g/m^3N	<0.01	1.15	0.26	98
	Total nitrogen	g/m^3N	0.19	1.51	0.61	97
	pH		6.6	8.7	7.6	93
L3 Hypolimnion	Dissolved reactive phosphorus	g/m^3P	<0.003	0.026	0.006	101
	Total phosphorus	g/m^3P	0.005	0.67	0.017	101
	Ammonia nitrogen	g/m^3N	<0.003	0.34	0.006	101
	Nitrite	g/m^3N	<0.001	0.020	0.001	91
	Nitrate	g/m^3N	0.05	1.00	0.58	95
	Total Kjeldahl nitrogen	g/m^3N	<0.01	1.63	0.16	99
	Total nitrogen	g/m^3N	0.30	2.2	0.76	98
	pH		6.5	7.2	6.8	95

Table 16 Nutrient water quality monitoring data for Lake Rotorangi site L2: Epilimnion (2016-2018)

Parameter	Unit	Date							
		20 Oct 2016	20 Feb 2017	22 Mar 2017	19 Jun 2017	18 Oct 2017	15 Feb 2018	22 Mar 2018	21 Jun 2018
Sample depth	m	8	3	4	6	5	3	2	5
Dissolved reactive phosph.	g/m^3P	0.015	0.005	0.005	0.006	0.013	<0.003	0.008	<0.004
Total phosphorus	g/m^3P	0.062	0.074	0.031	0.026	0.044	0.019	0.052	0.094
Ammonia-N	g/m^3N	0.052	0.018	0.024	0.004	0.057	0.032	0.054	0.020
Nitrite	g/m^3N	0.015	0.005	0.006	0.009	0.013	0.002	0.001	0.006
Nitrate	g/m^3N	0.60	0.20	0.18	0.67	0.62	0.07	0.64	0.50
TKN	g/m^3N	0.21	0.21	0.13	0.12	0.21	0.08	0.54	0.48
Total nitrogen	g/m^3N	0.83	0.42	0.32	0.80	0.84	0.15	1.18	0.85
pH	pH	7.4	7.4	7.3	7.1	7.4	7.6	7.2	7.7

Table 17 Nutrient water quality monitoring data for Lake Rotorangi site L2: Hypolimnion (2016-2018)

Parameter	Unit	Date							
		20 Oct 2016	20 Feb 2017	22 Mar 2017	19 Jun 2017	18 Oct 2017	15 Feb 2018	22 Mar 2018	21 Jun 2018
Sample depth	m	34	32	14	30	16	17	27	17
Dissolved reactive phosph.	g/m^3P	0.009	0.005	0.005	0.008	0.015	<0.003	0.008	<0.004
Total phosphorus	g/m^3P	0.038	0.053	0.017	0.020	0.053	0.017	0.060	0.108
Ammonia-N	g/m^3N	<0.003	0.022	0.004	0.052	0.068	<0.003	0.095	0.022
Nitrite	g/m^3N	0.002	0.002	0.002	0.009	0.011	0.001	0.001	0.006
Nitrate	g/m^3N	0.85	0.69	0.53	0.68	0.52	0.67	0.41	0.48
TKN	g/m^3N	0.14	0.03	0.01	0.14	0.26	0.04	0.27	0.51
Total nitrogen	g/m^3N	0.99	0.72	0.54	0.82	0.78	0.71	0.68	0.88
pH	pH	6.9	6.6	6.8	7.2	6.9	6.8	6.7	7.1

Table 18 Nutrient water quality monitoring data for Lake Rotorangi site L3: Epilimnion (2016-2018)

Parameter	Unit	Date							
		20 Oct 2016	20 Feb 2017	22 Mar 2017	19 Jun 2017	18 Oct 2017	15 Feb 2018	22 Mar 2018	21 Jun 2018
Sample depth	m	10	3	5	6	4	4	3	3
Dissolved reactive phosph.	g/m^3P	0.013	<0.003	0.003	0.008	0.015	<0.003	0.003	0.005
Total phosphorus	g/m^3P	0.040	0.018	0.020	0.025	0.027	0.022	0.018	0.020
Ammonia-N	g/m^3N	0.032	0.012	0.007	<0.003	0.015	0.011	0.011	<0.005
Nitrite	g/m^3N	0.011	0.002	0.003	0.001	0.009	0.002	0.007	0.002
Nitrate	g/m^3N	0.50	0.20	0.13	0.67	0.62	0.03	0.31	0.74
TKN	g/m^3N	0.26	0.13	0.14	0.19	0.09	0.15	0.21	0.23
Total nitrogen	g/m^3N	0.77	0.33	0.27	0.86	0.72	0.18	0.53	0.91
pH	pH	7.2	7.7	7.5	7.1	7.4	7.9	7.2	7.2

Table 19 Nutrient water quality monitoring data for Lake Rotorangi site L3: Hypolimnion (2016-2018)

Parameter		Date							
	Unit	20 Oct 2016	20 Feb 2017	22 Mar 2017	19 Jun 2017	18 Oct 2017	15 Feb 2018	22 Mar 2018	21 Jun 2018
Sample depth	m	47	30	28	40	29	21	21	29
Dissolved reactive phosph.	g/m^3P	0.011	0.006	0.006	0.004	0.012	<0.003	0.005	0.005
Total phosphorus	g/m^3P	0.020	0.032	0.017	0.011	0.025	0.013	0.026	0.020
Ammonia-N	g/m^3N	<0.003	<0.003	<0.003	<0.003	0.004	<0.003	<0.003	0.046
Nitrite	g/m^3N	0.001	<0.001	0.001	<0.001	0.002	0.001	<0.001	0.010
Nitrate	g/m^3N	0.89	0.70	0.68	0.66	0.78	0.71	0.54	0.65
TKN	g/m^3N	0.09	0.02	<0.01	0.06	<0.06	<0.01	0.05	0.21
Total nitrogen	g/m^3N	0.98	0.72	0.68	0.72	0.84	0.63	0.59	0.83
pH	pH	6.9	6.8	6.7	6.7	6.9	6.8	6.9	6.9

3.1.4.2 Epilimnion

The nutrient concentrations of the epilimnetic waters of the main lake (sites L2 and L3) were again characterised by relatively low levels of available plant nutrients (Table 16 and Table 18) 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 2017, and summer 2018). Total phosphorus concentrations have varied in the past in association with temporal and spatial fluctuations in suspended solids concentrations. These variations were apparent in winter 2018 at site L2, where turbidity increased markedly after a 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, though this was attenuated somewhat in summer 2017 and autumn 2018 by a recent large fresh. pH levels were slightly elevated at this time (7.3 to 7.9), consistent with a small increase in mid and lower lake sites' phytoplankton photosynthetic activity (e.g. up to 102% dissolved oxygen saturation of the surface waters, (Table 8). Partial mixing of the lake waters, plus the influence of river freshes, resulted in increases in certain nutrient concentrations and lower pH values (7.1 to 7.2) in mid winter at mid and lower lake sites in 2017 and the lower lake site in 2018.

3.1.4.3 Hypolimnion

The onset of anoxic conditions in the hypolimnetic waters during stratification resulted in increases in ammonia-N levels during the summer-autumn period at site L2 (Table 17 and Table 19), but not at site L3 where complete anoxia was not recorded over this period. but elevated ammonia-N level did occur at site L2 in winter. pH levels were consistently close to neutral (6.7 to 7.2 units), often significantly lower (by up to 1.1 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 winter when the lake was mixed.

The lengthy period of partial to complete stratification at sites L2 and L3 contributed to the variability in nutrient concentrations. The total phosphorus levels at sites L2 and L3 showed some variability in relation to changes in turbidity, particularly at site L2 in winter 2018, caused by suspended sediment settling through the hypolimnetic waters.

3.1.4.4 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 20.

Table 20 Statistical summary of nutrients and related data during late summer-autumn in the lower hypolimnion in relation to comparative hypolimnetic data at sites L2 and L3 from 1996 to June 2016

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	40	<0.003	0.040	0.008	40	<0.003	0.017	0.008
	Total phosphorus	g/m^{3}P	40	0.012	0.28	0.022	40	0.008	0.220	0.020
	Ammonia nitrogen	g/m^{3}N	40	0.015	0.62	0.148	40	0.005	0.297	0.110
	Nitrate + nitrite	g/m^{3}N	35	<0.01	0.70	0.43	37	0.02	0.72	0.46
	Temperature	°C	40	8.1	14.3	9.4	40	8.1	14.4	9.6
	Turbidity	NTU	40	2.4	310	9.0	40	1.6	230	3.8
	Dissolved oxygen	g/m^3	40	0.0	6.4	0.1	40	0.0	7.6	0.1
	pH		31	6.5	7.0	6.7	40	6.5	7.3	6.8
L3	Dissolved reactive phosphorus	g/m^{3}P	39	<0.003	0.032	0.007	39	<0.003	0.024	0.006
	Total phosphorus	g/m^{3}P	39	0.008	0.298	0.022	39	0.006	0.082	0.016
	Ammonia nitrogen	g/m^{3}N	39	<0.003	0.111	0.007	39	<0.003	0.064	0.006
	Nitrate + nitrite	g/m^{3}N	35	0.12	0.73	0.57	39	0.17	0.78	0.60
	Temperature	°C	39	7.4	14.7	9.2	39	7.7	14.9	9.3
	Turbidity	NTU	38	0.7	140	9.1	39	0.7	65	1.8
	Dissolved oxygen	g/m^{3}P	39	0.0	3.5	0.7	39	0.0	4.8	1.6
	pH		29	6.6	7.0	6.8	39	6.6	7.1	6.8

Historical median data (1996-2016) 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 2017 and March 2017, and in February 2018 and March 2018, are summarised in Table 21 and Table 22 and may be compared with results of samples collected from higher up the water column within the hypolimnion on the same occasion (Table 17 and Table 19).

Table 21 Nutrient water quality monitoring data for Lake Rotorangi sites L2 and L3: lower hypolimnion (above the lake bed) in the 2016-2017 period

Site		L2		L3	
Parameter	**Unit**	**20 Feb 2017**	**22 Mar 2017**	**20 Feb 2017**	**22 Mar 2017**
Sample depth	m	37	37	50	49
Dissolved reactive phosphorus	g/m^3P	0.004	0.004	0.006	0.005
Total phosphorus	g/m^3P	0.049	0.019	0.061	0.015
Ammonia-N	g/m^3N	0.034	0.082	<0.003	0.005
Nitrate + nitrite-N	g/m^3N	0.75	0.52	0.77	0.66
[Dissolved oxygen]	g/m^3	[0.1]	[0.1]	[2.1]	[1.8]
[Turbidity]	NTU	[2.7]	[2.4]	[4.5]	[3.0]
[pH]		[6.6]	[6.6]	[6.6]	[6.6]
[Total BOD_5]	g/m^3	-	-	-	-

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

Table 22 Nutrient water quality monitoring data for Lake Rotorangi sites L2 and L3: lower hypolimnion (above the lake bed) in the 2017-2018 period

Site		L2		L3	
Parameter	**Unit**	**15 Feb 2018**	**19 Mar 2018**	**15 Feb 2018**	**19 Mar 2018**
Sample depth	m	37	38	50	50
Dissolved reactive phosphorus	g/m^3P	0.009	0.006	0.006	0.004
Total phosphorus	g/m^3P	0.034	0.040	0.017	0.015
Ammonia-N	g/m^3N	0.34	0.109	<0.003	0.010
Nitrate + nitrite-N	g/m^3N	0.14	0.41	0.61	0.66
[Dissolved oxygen]	g/m^3	[0.1]	[0.2]	[0.3]	[0.2]
[Turbidity]	NTU	[21]	[8.7]	[3.1]	[2.3]
[pH]		[6.8]	[6.7]	[6.7]	[6.7]
[Total BOD_5]	g/m^3	-	-	-	-

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

During the summer stratification period anoxic conditions were present in the lower hypolimnion at site L2 but not at site L3 (see Figure 8 and Figure 9). Both sites showed no significant increases in dissolved reactive phosphorus in the lower hypolimnetic waters near the sediment interface (Table 21) compared with higher in the water column of the hypolimnion (Table 17 and Table 19), but an increase in total phosphorus at site L3 in February 2017 when there was an increase in turbidity. Increases in ammonia nitrogen (0.034 and 0.082 g/m^3N in 2017, and 0.34 and 0.11 in 2018 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 in either year.

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 21) were within the ranges of historical data (Table 20) measured during summer-autumn anoxic and near anoxic conditions, except nitrate-N at site L2 in February 2017 (0.75 g/m^3N), which exceeded the highest previous value (0.70 g/m^3N), recorded in February 2016. Total phosphorus did not increase significantly in either year, when turbidity indicated minimal change in fine suspended sediment in the water column near the lakebed. Ammonia-N was present above median values under anoxic conditions on one occasion, at site L2 in February 2018.

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

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

3.1.4.5 General

Nutrient data surveyed during the 2016-2017 and 2017-2018 monitoring periods 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 1990-2017 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-six 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).

3.1.4.6 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, 2017, 2018). 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 survey occasion. These results are presented in Table 23 and Table 24.

Table 23 Bacteriological quality monitoring data for Lake Rotorangi site L2: surface water (2016-2018)

Site		Date							
Parameter	**Unit**	**20 Oct 2016**	**20 Feb 2017**	**22 Mar 2017**	**19 Jun 2017**	**18 Oct 2017**	**15 Feb 2018**	**22 Mar 2018**	**21 Jun 2018**
Time	NZST	0845	0925	0840	0955	0850	0910	1015	1030
Temperature	˚C	15.6	21.5	19.7	11.5	14.7	23.8	19.0	11.1
Turbidity	NTU	5.0	1.4	1.2	4.1	2.8	1.2	7.4	
E.coli	/100 mL	34	41	7	8	46	20	27	
Enterococci	/100mL	<1	4	<1	2	1	2	10	

Table 24 Bacteriological water quality monitoring data for Lake Rotorangi site L3: Surface (2016-2018)

Site		Date							
Parameter	**Unit**	**20 Oct 2016**	**20 Feb 2017**	**22 Mar 2017**	**19 Jun 2017**	**18 Oct 2017**	**15 Feb 2018**	**22 Mar 2018**	**21 Jun 2018**
Time	NZST	1100	1045	1015	1135	1035	1105	1205	1250
Temperature	˚C	16.4	21.7	20.4	11.6	15.0	24.4	19.6	11.1
Turbidity	NTU	2.1	0.8	0.9	3.6	3.2	1.1	1.5	
E.coli	/100 mL	2	9	1	9	1	9	2	
Enterococci	/100mL	6	62	5	2	1	<1	<1	

Bacteriological water quality was well within the guidelines for contact recreation (MfE, 2003) at both sites on all sampling occasions. Sparse birdlife has been noted on the water in the vicinity of sites L2 and L3 in previous surveys 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 2016-2017 and 2017-2018 monitoring periods 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 April 2018, 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 2016, February, March, June and October 2017, and February, March and June 2018. The phytoplankton samples were preserved with Lugol's iodine solution and all samples were later identified under a compound microscope using up to 400 x magnification.

Benthic macroinvertebrate samples were collected by Ekman dredge from the lakebed at sites L2 and L3 in conjunction with the survey of October 2017, as a long-term component of the monitoring programme.

These samples were run through a 0.5 mm sieve, before being sorted and identified under a stereoscopic microscope.

3.2.2 Results

3.2.2.1 Lake phytoplankton communities

Phytoplankton samples were collected from Lake Rotorangi on 20 October 2016, and 20 February, 22 March, 19 June and 18 October 2017, and 15 February, 22 March and 21 June 2018. These samples were taken from within the photic zone (surface waters) of sites L2 and L3. Table 25 and Table 26 list the phytoplankton taxa found at each site during the two years. 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 25 Phytoplankton found at site L2 in Lake Rotorangi during the 2016-2018 period

Date	20 Oct 2016	20 Feb 2017	22 Mar 2017	19 Jun 2017	18 Oct 2017	15 Feb 2018	22 Mar 2018	21 Jun 2018
GREEN ALGAE								
Unidentified (unicellular)	P	P	P	P		P	P	P
Closterium	P							
Ankistrodesmus		P						
Tetraedon							P	
Coelastrum			P					
Micractinium				P				
Eudorina							P	
CYANOBACTERIA								
Anabaena					P			
DIATOMS								
Synedra			P					
Navicula		P						
Cymbella							P	
Aulacoseira							P	
Fragilaria							P	
GOLDEN BROWNS								
Dinobryon							P	
Synura	P							
EUGLENOIDS								
Trachelomonas	P	P	P	P	P	P		
CRYPTOPHYTES								
Cryptomonas	P						P	
TOTAL	5	4	4	3	2	2	8	1

P – Present

A - Abundant

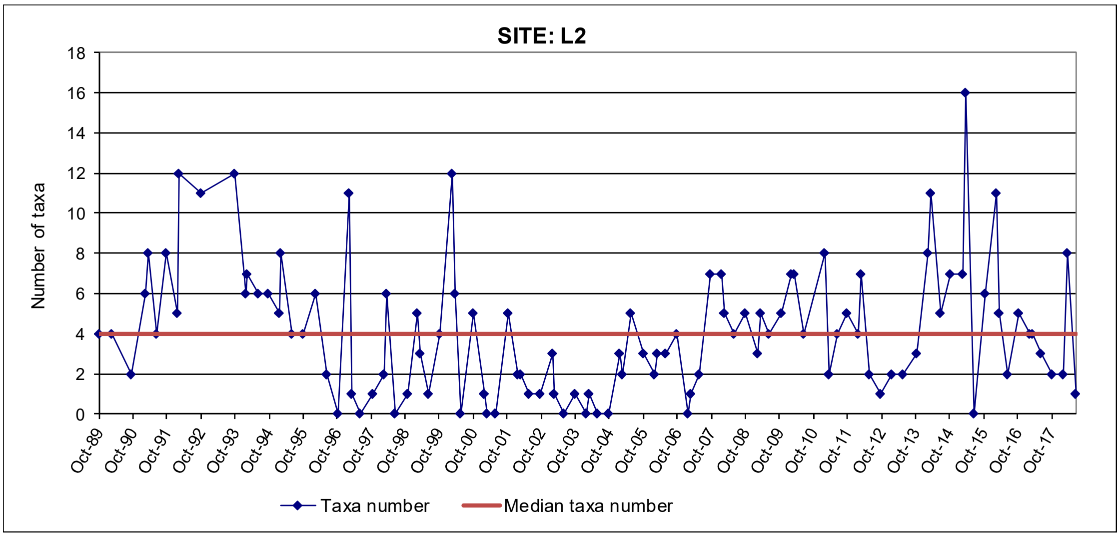


Figure 11 Number of phytoplankton taxa recorded at site L2 in Lake Rotorangi since monitoring began in 1989

Moderate numbers of taxa (3 to 5) were recorded at site L2 during the 2016-2017 monitoring period, around the historical median richness (4 taxa) on each occasion (Figure 11). Chlorophyll-a concentrations had a narrow range (3.8 to 4.4 mg/m^3 (Table 13)). Only one individual taxon was present on more than one survey occasion (euglinoid *Trachelomonas*, on three occasions) and no taxon was recorded as abundant.

A wider range of taxa (1-8) was recorded at site L2 during the 2017-2018 monitoring period. Chlorophyll-a concentrations had a wide range (2.5 to 10.7 mg/m^3), the highest level coincident with maximum taxa richness during late summer. Only one individual taxon (euglinoid *Trachelomonas*) was present on two occasions, and no taxon was recorded as abundant.

3.2.2.1.2 Site L3

A moderate range of numbers of taxa was found at L3 during the 2016-2017 monitoring period, similar to, or above, the historical median (3 taxa) richness. Three taxa were present on the late-summer sampling occasion, (Figure 11), coincident with a low chlorophyll-a concentration (1.7 mg/m^3), whereas higher richnesses in spring, autumn and winter were coincident with higher chlorophyll-a concentrations (3.1 to 5.1 mg/m^3).

Table 26 Phytoplankton found at site L3 in Lake Rotorangi in the 2016-2018 period

Date	20 Oct 2016	20 Feb 2017	22 Mar 2017	19 Jun 2017	18 Oct 2017	15 Feb 2018	22 Mar 2018	21 Jun 2018
GREEN ALGAE								
Unidentified (unicellular)	P	P	P	P	P		P	P
Closterium	P		P					
Ankistrodesmus					P			
Tetraedon							P	
Chlorogonium							P	
Coelastrum				P				
Micractinium				P	P			
Eudorina	P						P	
Scenedesmus						P		
Actinastrum				P				
Selenastrum						A		
CYANOBACTERIA								
Anabaena			P	P				
Microcystis			A	A				
DIATOMS								
Synedra			A					
Aulacoseira							P	
Fragilaria		P	P				P	
GOLDEN BROWNS								
Dinobryon						P	P	
Synura					P			
DINOFLAGELLATES								
Ceratium			P					
EUGLENOIDS								
Trachelomonas	A	P	P	P	P			
CRYPTOPHYTES								
Cryptomonas	P						P	
TOTAL	5	3	8	7	5	3	8	1

P – Present

A – Abundant

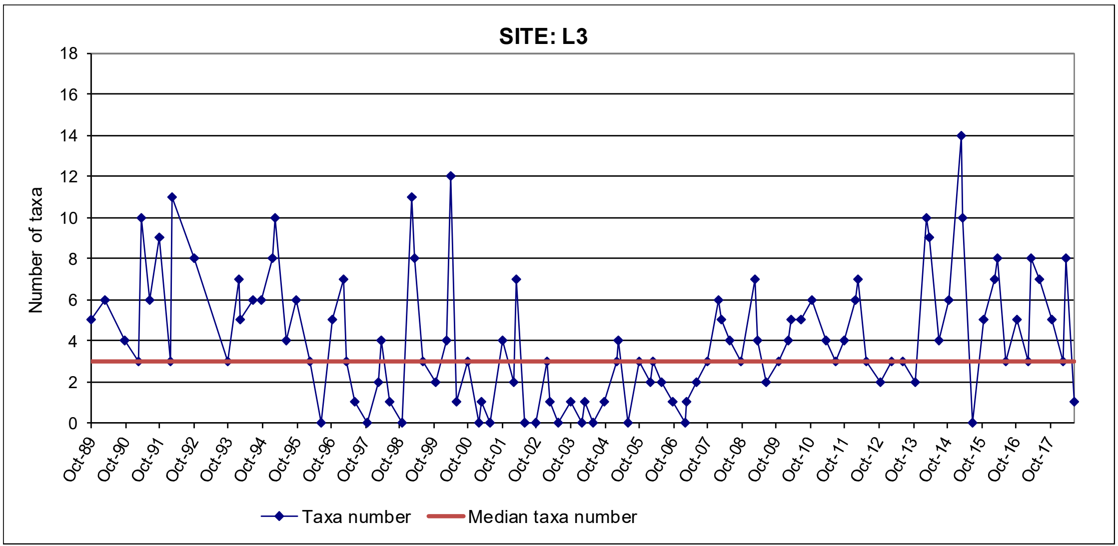


Figure 12 Number of phytoplankton taxa recorded at site L3 in Lake Rotorangi since monitoring began in 1989

In 2016-2017, one individual taxon was present on all four occasions (euglinoid *Trachelomonas),* and three taxa (green alga *Closterium*, and cyanobacteria *Anabaena* and *Microcystis*) were present on two occasions. Two taxa (cyanobacteria *Anabaena* and *Microcystis*) were abundant at the time of the autumn survey, and one taxon was abundant at the time of the spring (euglenoid *Trachelomonas*) and winter (cyanobacterium *Microcystis*) surveys.

Moderate numbers of taxa was found at L3 during the 2017-2018 monitoring period, similar to or above the historical median (3 taxa) richness, with the exception of a single (unidentified) taxon present following the mid-winter, 2018 flood event. Taxon number did not correlate well with chlorophyll-a concentration, which reduced from 13.0 mg/m³ in spring to <3 mg/m³ in winter.

In 2017-2018, one individual taxon was present on two occasions (golden brown alga *Dinobryon*), and one taxon (green alga *Selenastrum*) was abundant at the time of the late summer survey.

3.2.2.1.3 General comments

Phytoplankton density limiting factors include:

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

The absence of significant blooms of algae to date has indicated that one or more of these limiting factors have prevented algal population increases from continuing for long periods of time. Phytoplankton survey results to date indicate that the open-water algal community composition of Lake Rotorangi is determined by the ability of opportunist taxa to proliferate during the very limited periods of favourable conditions. Phytoplankton provides the food source for the microscopic crustacea in the open water (the major component of zooplankton). Such zooplankton taxa as cladocerans *Daphnia* and *Ceriodaphnia* have been recorded in highly variable densities in Lake Rotorangi in past years. Large numbers of these cladocerans have been recorded in the stomachs of perch (*Perca fluviatilis*) taken from Lake Rotorangi. Some of the algal taxa recorded in the lake phytoplankton are likely to have drifted downstream from the discharge from the

Stratford oxidation pond system (where extensive algal populations are a feature of the biological treatment system), and from the mid-reaches of the Patea River. [Note: A major upgrade to the Stratford wastewater treatment plant in 2009 has been designed to reduce the algal population component of the effluent discharge to the river downstream of Stratford (TRC, 2018a)].

In summary, low to moderate taxonomic richnesses was found at both sites throughout the 2016-2017 and 2017-2018 monitoring years with only four algal taxa, two on one occasion, found in abundance at either site. Taxa richnesses on all survey occasions were similar to or up to five more than the running median number of taxa recorded for each site to date. Phytoplankton results indicate that lake phytoplankton community composition is determined by opportunistic taxa which have the ability to proliferate during favourable conditions (e.g. late summer/autumn) and these conditions may be confined to very limited periods.

3.2.2.2 Benthic macroinvertebrate fauna

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

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

The initial sampling of the lake bed at the deeper sites (L2 and L3) was undertaken in October 1992 with samples collected at similar times over subsequent years until the October 2013 survey using an Ekman dredge. Following the October 2013 survey, the frequency of monitoring was reduced to triennial sampling, and the current (October 2017) survey was the first survey at the reduced frequency. The macroinvertebrate taxa found over the period to October 2017 in the lake benthos are summarised in Table 27.

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 and at site L3 in the current survey. No crustaceans, molluscs or dipterans were recorded at either site L2 or site L3 in the current survey.

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.

Table 27 Macroinvertebrate fauna of the Lake Rotorangi benthos at sites L2 and L3

Date	Oct 1992		Jun 1994		Sep 1994		Oct 1995		Oct 1996		Oct 1997		Nov 1998		Oct 1999		Oct 2000		Oct 2001		Oct 2002		Oct 2003	
Site	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3
ANNELIDA																								
Oligochaeta	XA	C	C	A	A	XA	XA	XA	C	C	XA	A	XA	C	VA	VA	VA	A	XA	A	A	C	C	R
Branchiura	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MOLLUSCA																								
Potamopyrgus	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	R	R	-	-
Physa	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-			-	-
CRUSTACEA																								
Copepoda	R	-	-	-	-	-	-	-	-	-	-	-	R	-	R	-	-	-	-	-	-	-	R	-
Cladocera	R	-	-	-	-	-	-	-	-	-	-	-	R	-	R	-	R	-	-	-	-	-	-	-
Ostracoda	C	-	-	-	-	-	-	-	-	-	-	-	R	-	R	-	C	-	-	-	C	-	C	-
DIPTERA																								
Orthocladiinae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tanypodinae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
C.zealandicus	R		-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	R	-	R	-	-	C	-
ACARINA		-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	R	-	-	-	-	-	-	-
Number of taxa	5	1	1	1	1	1	1	1	1	1	3	1	4	1	5	1	5	2	1	2	3	2	4	1

Date	Oct 2004		Oct 2005		Oct 2006		Oct 2007		Oct 2008		Oct 2009		Oct 2010		Oct 2011		Oct 2012		Oct 2013		Oct 2017	
Site	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3	L2	L3
ANNELIDA																						
Oligochaeta	A	A	XA	R	A	A	A	A	A	A	C	A	C	C	A	A	A	A	-	-	XA	VA
Branchiura	-	-	-	-	C	-	-	-	-	R	R	-	-	-	-	-	-	-	-	-	-	R
MOLLUSCA																						
Potamopyrgus	-	-	R	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Physa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CRUSTACEA																						
Copepoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cladocera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracoda	-	-	R	-	-	R	-	-	-	-	-	-	-	-	-	-	R	R	C	-	-	-
DIPTERA																						
Orthocladiinae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-
Tanypodinae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-
C.zealandicus	R	R	R	-	-	-	-	-	-	-	-	-	-	-	R	R	-	-	R	-	-	-
ACARINA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-
Number of taxa	2	2	4	1	2	3	1	1	1	2	2	1	1	1	2	2	2	4	2	0	2	2

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

3.2.2.3 Aquatic macrophyte survey

The latest survey of the aquatic macrophytes in Lake Rotorangi was performed on 15 April 2018. 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 13 and discussed beneath. There had been a significant fresh in the upper catchments three days before. The survey began at the Mangamingi boat ramp and the true right bank was surveyed on the way down the lake to the Patea Dam. The true left bank was surveyed on the way back up. None of the tributaries or arms of the lake was entered. At regular intervals the macrophyte species seen on the lake edges were recorded on a map of Lake Rotorangi, and the dominant species noted. The dominant taxa were then colour-coded and their distributions are shown in Figure 13, with previous data shown in Figure 14. It should be noted that the current survey was hindered by high turbidity and high water level (77.5 m asl). This prevented identification of sub-surface macrophytes, and resulted in some areas of the lake having no macrophytes identified.

Previous macrophyte monitoring, which began in March 1987, found Egeria densa dominating the greatest proportion of the lake edges, increasing as time progressed (Figure 14). 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. In previous surveys, E. densa has always dominated the upper end of the lake. The currently reported survey recorded less macrophyte than was recorded in 2015, with no macrophyte observed throughout the mid-section of the lake (Figure 13). It is probable that this was caused by the high turbidity at the time of the survey. Only E. densa and Ceratophyllum demersum (Photo 1) were recorded in the current survey. It is of note that E. densa was recorded only at the lower end of the lake near the boat ramp, and not near the upper end of the lake as in previous surveys.

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

The macrophyte survey undertaken in 2012 was the first to document C. demersum in Lake Rotorangi. Since this survey, when C. demersum was only dominant on the true left bank downstream of the Hawera water ski club rooms, its distribution has increased markedly, as predicted in a report prepared by NIWA1. As predicted in the previous report, C. demersum was the dominant macrophyte in this survey. However, given the high turbidity, it is possible that it may have been present throughout the mid-section of the lake where no macrophytes were recorded. Lagarosyphon major was not recorded as dominant in the current survey despite being found as dominant in some smaller areas during the 2015 survey.

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.

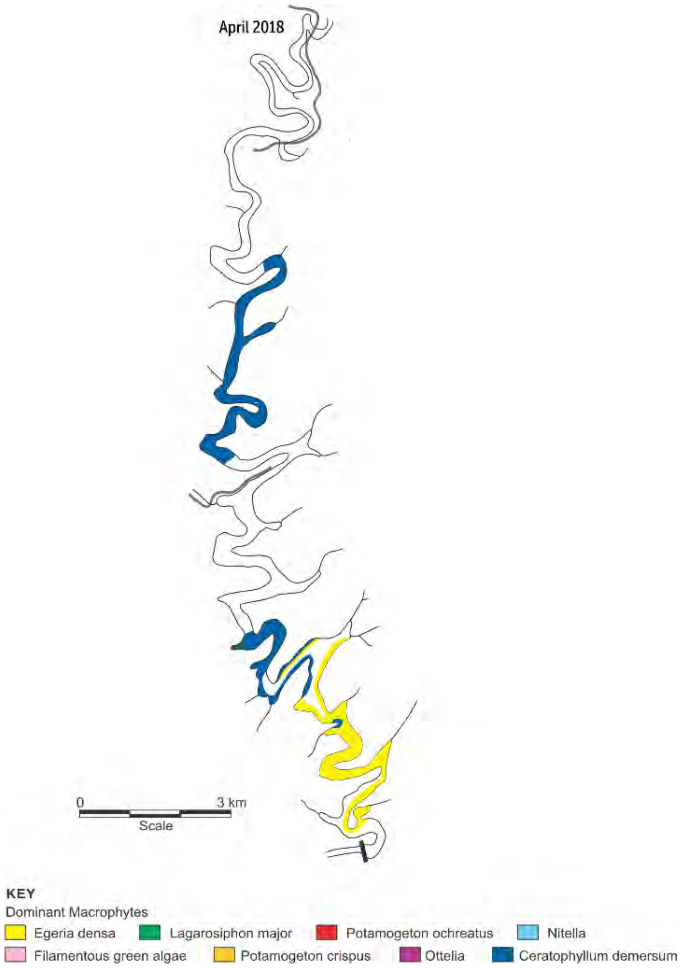


Figure 13 Dominant macrophytes in Lake Rotorangi, 2018

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

[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.

E. densa tends to thrive in turbid and enriched waters of lakes, whereas L. major is more common in clear water lakes of low fertility. It is interesting to note that the 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 often been 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. L. major was not recorded in the 2018 survey, which was undertaken at the end of a wet summer, and high turbidity was noted during this survey. This absence may have been a result of the high turbidity, either due to preventing the observation of this species or, although perhaps less likely, it being truly absent in the turbid conditions.

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.

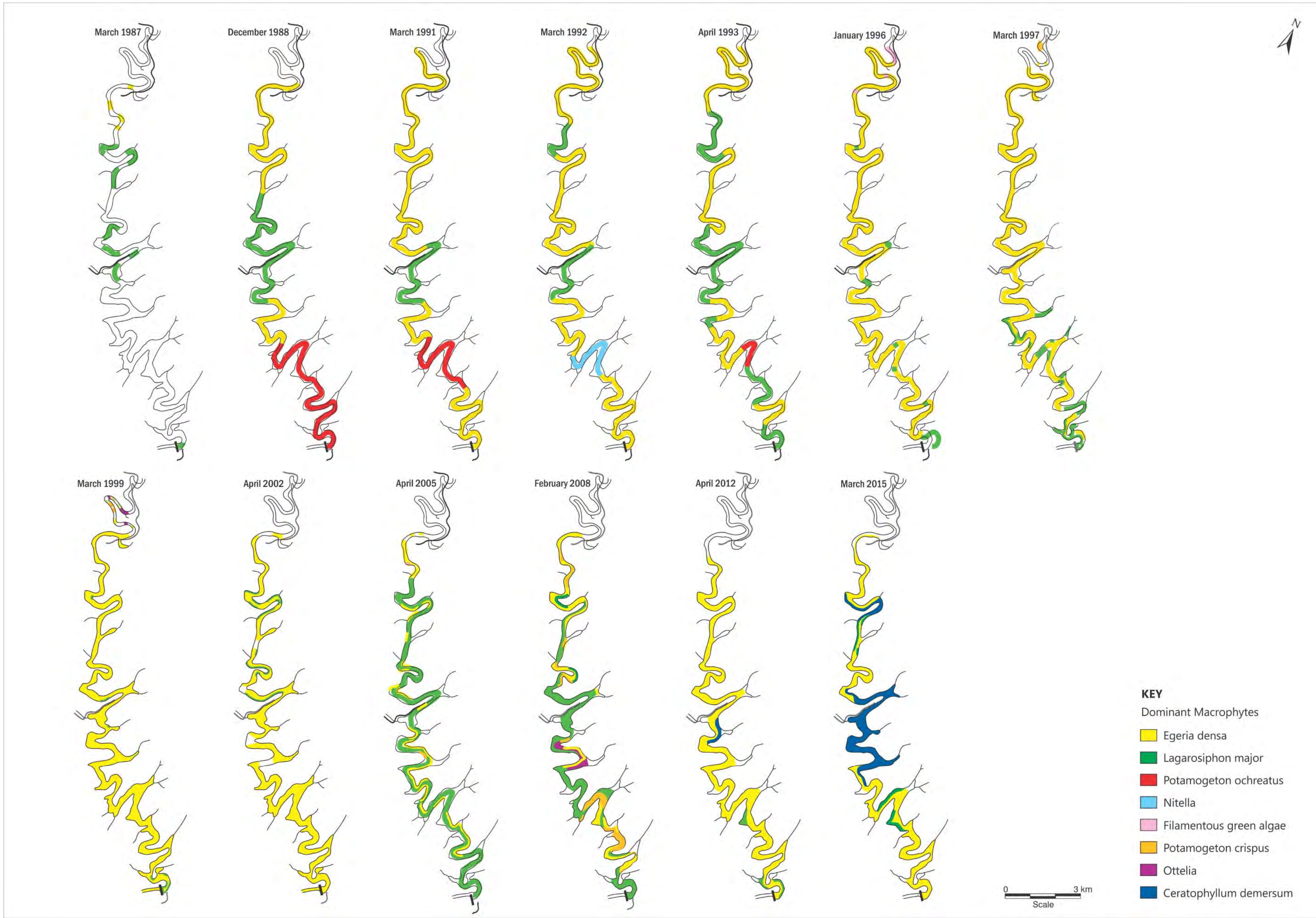

Figure 14 Dominant macrophytes in Lake Rotorangi from March 1987 to April 2015

A summary of the aquatic macrophyte species found in Lake Rotorangi by the summer – autumn surveys performed between 1986 and 2018 is presented in Table 28.

Table 28 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	Apr-18
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 32 years of the survey period. Two macrophytes (*E. densa* and *L. major*) have been recorded on all previous survey occasions, although *L. major* was not present in the current survey, as discussed previously. Another species frequently recorded is *P. crispus*, with this species even dominating parts of the lake in 2008. However, in the previous survey, this species was only noted at the very head of the lake, and in the current survey it was not recorded. This may be influence by the large rudd (*Scardinius erythrophthalmus*) population in the lake. A study undertaken in 2002[3] of rudd, an omnivorous fish, found that, of nine macrophytes tested, rudd preferred eating *Potamogeton ochreatus* over *E. densa* and *L. major*, while *C. demersum* was least preferred. Although *P. crispus* was not included in this study, its similar appearance to *P. ochreatus* may indicate that it would also be preferentially eaten by rudd (an omnivorous fish), and this may explain its reduced abundance in Lake Rotorangi in recent years.

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

A survey undertaken by NIWA in 2012 recorded four macrophyte species not previously recorded in the lake. It is unlikely that these species are new additions to the lake, only that they were not previously observed. This is because they were either not widespread, or had growth habits/forms that caused them to be relatively discreet e.g. low growing plants that inhabit deep water. They were therefore very difficult to observe or differentiate during a moving survey, and consequently were only recorded when the boat was stationary (*G. elatinoides*) or by divers (*C. australis, L. ruthiana* & *N. cristata*). It is unlikely that these species will ever become abundant.

C. demersum is considered highly invasive, and is expected to eventually become dominant, out-competing *E. densa* and *L. major*. While this is not expected to cause significant impacts on the ecology of Lake Rotorangi or on the hydroelectric scheme, there is now greater potential for it to spread to nearby lakes, where such impacts could be much more severe, e.g. Lake Rotokare. In response to the proliferation of this high-risk species, the Council intensified biosecurity advocacy and education under the 'Check, Clean, Dry' programme that it runs in conjunction with the Ministry of Primary Industries and the Department of Conservation.

In summer 2015-2016, larger signs were erected at the three boat entrances to Lake Rotorangi, at Mangamingi, Tangahoe and the Dam, and new signs specifically about *C. demersum*, or hornwort, were added (Photo 2). Clubs and organizations were visited, freshwater events attended, and media releases made to raise awareness about freshwater pests. A survey of water users indicated that, while there was a high awareness around freshwater pests, there was a lack of knowledge about *C. demersum*, which continued to be addressed through the ongoing regional Check Clean, Dry campaigns against freshwater pests that were carried out over summer 2016-2017 and 2017-2018 (TRC 2017b, 2018b).

Photo 2 Pest fish and plants sign at Tangahoe boat ramp

4 Conclusions

4.1 Discussion of 2016-2018 programme

4.1.1 Water quality

Pre-stratification, two summer stratification, and post-stratification (winter) sampling surveys were performed during each 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 in 2016-2017 and 2017-2018 with anoxic hypolimnetic water recorded at site L2 and oxygen depleted hypolimnetic water recorded at site L3 (i.e. during February-March 2017 and 2018). Normal lake overturn was complete at site L2 but only partially complete at site L3 in mid-winter (June 2017 and 2018). 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 1995-1996 period and subsequent follow-up reports (Burns, 1999; Burns et al, 2000 and Burns, 2006) and the most recent trend evaluation for the period 1990 to 2016 (Appendix II) which was carried out by the Council. However, relatively high turbidity levels (caused by riverine derived fine silt) from time to time have increased total phosphorus and nitrogen levels and lowered secchi disc values, indicative of a trend toward slightly eutrophic conditions (Burns, 2006). Nutrient supply has been limited principally to those quantities present in the river inflow waters. Despite low dissolved oxygen concentrations and periods of anoxic conditions in the lower waters of the hypolimnion, minimal increases in nutrient concentrations in these waters (usually due to the increased solubility of nutrients from sediments and decomposing vegetation under reducing conditions), have been recorded, with the main variations relating to relatively small increases in ammonia levels measured during this period with minor changes in total phosphorus levels (usually coincident with increased turbidity due to fine sediment).

Variability in levels of turbidity and suspended solids concentrations at the times of the eight 2016-2018 surveys were related to the recency of river freshes. Freshes prior to the autumn and winter 2018 surveys in particular increased turbidity, reducing secchi disc transparency at both sites in the lake, but more so at the mid-lake site L2. As has been noted in the past, lake surface water suspended solids concentrations generally were not excessive at mid and lower lake sites and were due to the finer colloidal material which remained suspended and would be expected to be carried through the lake.

The most recent lake water quality trend analysis, performed by the Council for the 26 year period 1990-2016 (see Appendix II) has continued to support the findings and conclusions of Burns, 2006. i.e. that the trophic level continues to increase at a very small, insignificant annual rate of change (0.01 $\pm$ 0.01 TLI units per year). However, given the tendency for the reservoir water to contain elevated (fine) silt levels, which artificially elevate the trophic index, the trophic category is more appropriately mesotrophic. This is further confirmed by mesotrophic chlorophyll-a level. The analysis also notes significant increase in the average concentration of chlorophyll-a and total phosphorus, but not the other key variables (secchi disc visibility and total nitrogen). The other variable showing a significant temporal trend was and nitrate, which is increasing.

4.1.2 Biology

No phytoplankton blooms were recorded in Lake Rotorangi. The lake has been unable to sustain significant abundances of planktonic algae for long due to the frequency of river freshes. Low to moderate numbers of algal taxa were recorded, partly as a result of the frequency of river freshes through the system. Several of the taxa that have been found to date probably originated from the Stratford oxidation pond wastewater treatment system discharge (where extensive algal populations have been a feature of the biological treatment system) and from the mid reaches of the Patea River. Phytoplankton results to date indicate that lake phytoplankton community composition is determined by opportunistic taxa which have the ability to proliferate during favourable conditions which may be confined to very limited periods often due to the frequency of river freshes moving down the lake. Chlorophyll-a concentrations in the lake were low to moderate at survey times with the exception of the spring 2017 survey at the lower lake site and the autumn 2018 survey at the mid lake site, when higher nutrient concentrations followed general river freshes.

The autumn 2018 macrophyte survey was conducted at a time of high turbidity throughout the length of the lake, caused by a recent fresh in the upper catchments, which may have affected the discovery of submerged plants. The oxygen weed *Egeria densa* was identified as the dominant macrophyte in the lower part of the lake, and *Ceratophyllum demersum* (hornwort) in parts of the mid-section. No other species was recorded as dominant, and only one other species, *Glossostigma elatinoides*, was found. *Lagarosiphon major*, which had been recorded in all previous surveys was not found, possibly as a result of the high turbidity. This is the third 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,* although this had not occurred at the time of the October 2018 survey. While this is not expected to cause significant impacts on the ecology of Lake Rotorangi or on the hydroelectric scheme, there is now greater potential for it to spread to nearby lakes, where such impacts could be much more severe e.g. Lake Rotokare. The next survey is due to be performed in the 2020-2021 period.

Appropriate warning signs about aquatic weeds, positioned at the three principal boat ramps along the lake's length, publicise the problems that could result from the introduction of further nuisance aquatic plants by recreational users, and their responsibilities for preventing the transportation of aquatic plants between the waterways. These were updated during the 2015-2016 period, with particular reference to hornwort.

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

4.2 2015-2016 Report's recommendations

The recommendation contained in the 2015-2016 Annual Report based upon the monitoring programme results was:

1. THAT the Lake Rotorangi physicochemical and biological water quality monitoring programme continue on an annual basis as a component of the Council's state of the environment monitoring programme, with every third year of the programme also undertaken in conjunction with the Patea Hydro Electric Power Scheme-aquatic monitoring plan (next in 2017-2018), and that the requisite macrophyte and benthic macroinvertebrate surveys be components of the 2017-2018 programme.

This recommendation (1) was implemented with the continuation of a state of the environment monitoring programme to include the physicochemical and biological water quality monitoring including the triennial performance of the macrophyte survey. Once every three years this will be undertaken at TrustPower's expense, as required by consent 0489, and this is included in the Patea Hydro Electric Power Scheme - aquatic monitoring plan.

4.3 Alterations to monitoring programme for 2018-2019

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 2020-2021 period. No alterations are required to the 2018-2019 programme, and it is noted that the designated macrophyte survey will next be undertaken in early 2021 and the benthic macroinvertebrate survey in spring 2020.

A recommendation to this effect is attached to this report.

5 Recommendation

The following recommendation is based on the results of the 2016-2017 and 2017-2018 water quality and biological monitoring programmes and the contractual requirements of the resource 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 2020-2021), and that the requisite macrophyte and benthic macroinvertebrate surveys be components of the 2020-2021 programme.

6 Acknowledgements

The programme Job Manager was Bart Jansma (Environmental Scientist). The principal author of the Annual Report was James Kitto (Science Advisor), who provided the statistical trend analyses. Field lake sampling and macrophyte surveys were performed by Bart Jansma assisted by boatpersons Brent Nicol and Regan Diggelmann. Hydrological data was provided by Fiona Jansma (Data Analyst). All water quality analytical work was performed by the Taranaki Regional Council ISO-9000 accredited laboratory under the supervision of John Williams, except the June 2018 samples, which were analysed by Hill Laboratories. Phytoplankton analyses were performed by Darin Sutherland (Environmental Scientist) in the Council's biology laboratory, and the macrophyte assessment was provided by Katie Blakemore (Technical Officer).

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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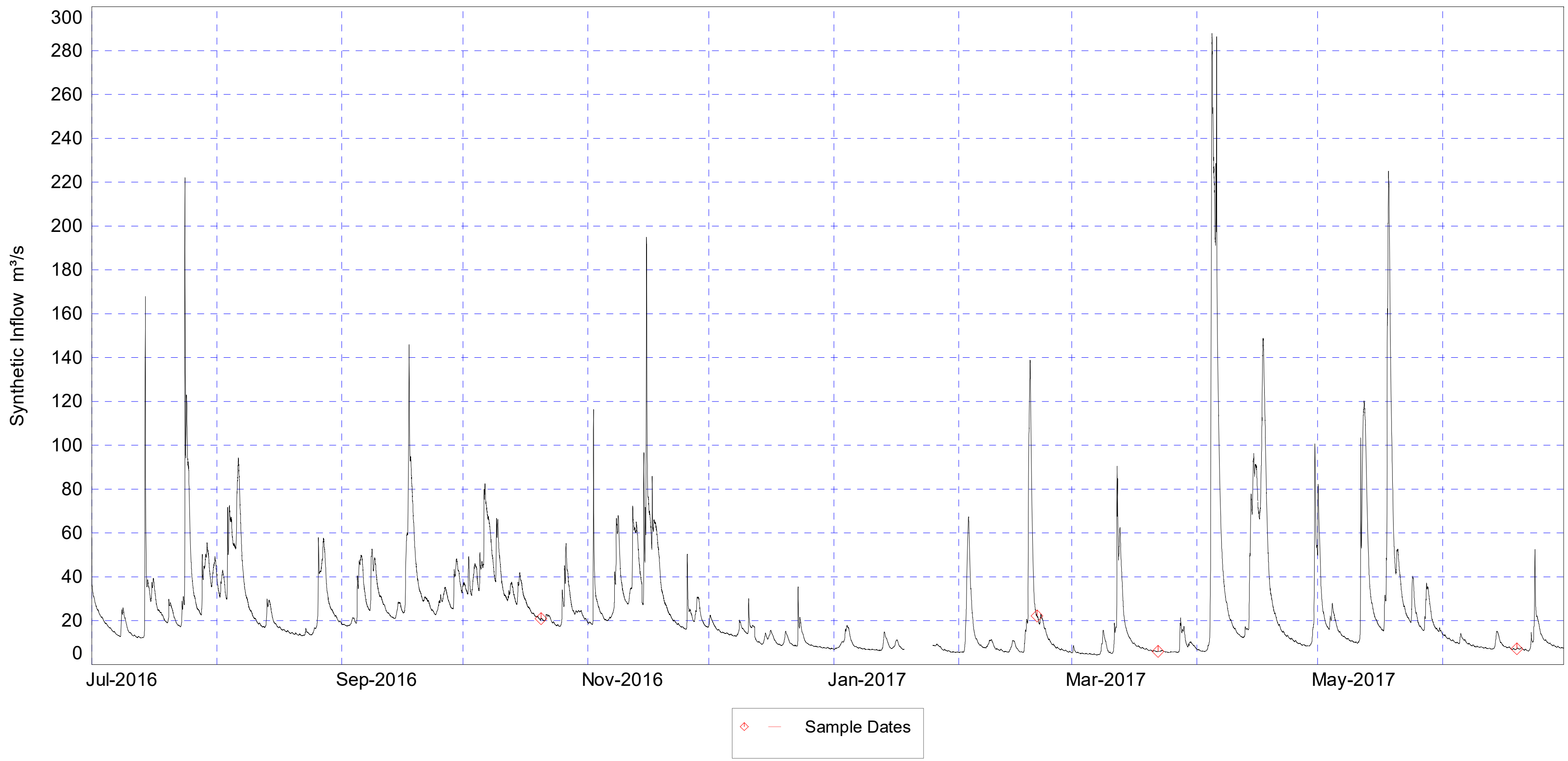
Appendix I

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 2016 to 30 June 2018

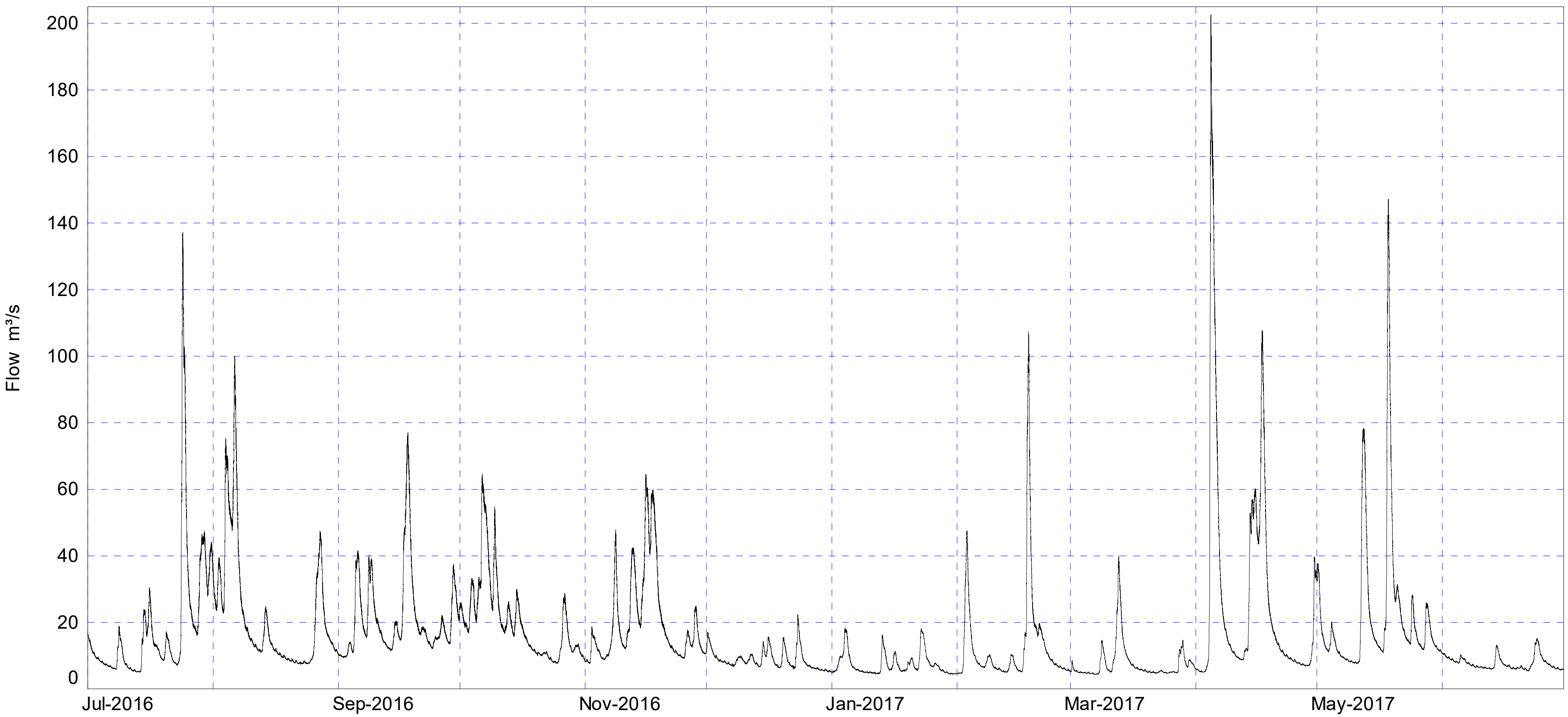


Synthetic inflow at Lake Rotorangi for the period 1 July 2016 to 30 June 2017

Source is R:\PROCESSING-FILE\WATER TAKES & DISCHARGES.hts
Synthetic Inflow (m3/sec) at Patea Dam
From 1-Jul-2016 00:00:00 to 30-Jun-2017 24:00:00
24 hour periods beginning at midnight each day.

Daily means Years 2016-2017 Synthetic Inflow(m3/sec) at Patea Dam

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
1	31.213	34.214	18.163	35.674	18.960	20.460	7.303	5.639	6.510	6.629	54.452	13.190	
2	24.728	39.700	17.769	37.316	40.619	17.535	8.672	13.561	5.422	6.054	23.450	11.774	
3	21.363	41.556	19.904	37.914	27.564	15.536	11.803	52.913	5.079	6.933	17.179	10.834	
4	18.651	64.920	23.526	40.686	22.835	14.547	16.311	21.303	4.923	126.255	23.285	9.948	
5	16.630	56.994	45.437	43.729	20.340	14.154	10.427	11.142	4.815	219.793	19.455	11.973	
6	14.842	80.929	37.155	68.923	21.293	13.547	8.079	8.595	4.617	110.704	14.661	10.948	
7	13.323	43.842	26.162	64.511	30.520	13.043	7.510	7.786	4.495	45.081	12.721	9.380	
8	21.016	29.734	43.246	46.758	60.727	16.588	7.120	9.960	9.877	27.287	11.565	8.618	
9	18.975	24.043	42.146	54.573	36.408	16.259	6.875	9.537	9.824	19.862	10.657	8.107	
10	14.443	20.717	31.484	41.647	28.846	16.876	6.817	6.995	5.477	16.082	10.050	7.897	
11	13.107	18.592	26.962	31.445	32.504	17.842	6.655	6.534	10.913	13.628	32.592	7.562	
12	12.504	17.224	23.427	32.619	61.895	13.649	6.546	5.877	52.570	12.727	107.784	7.304	
13	12.308	24.614	21.580	33.635	53.398	10.083	11.692	6.333	38.898	16.525	58.831	7.363	
14	57.031	24.612	23.407	31.566	41.891	10.455	9.737	10.045	16.786	64.628	27.765	13.296	
15	32.793	18.650	26.976	37.337	91.870	12.727	7.630	7.265	11.819	89.797	20.478	10.045	
16	34.473	16.869	30.113	29.483	65.626	14.247	10.146	5.739	9.447	72.903	17.005	8.133	
17	25.085	15.755	86.432	25.514	64.347	10.788	8.098	13.189	8.248	125.510	22.489	7.686	
18	22.364	15.051	76.692	23.027	52.230	9.105	?	92.803	7.535	66.894	159.851	6.999	
19	19.631	14.342	44.764	21.610	33.145	10.240	?	46.397	6.992	31.472	94.039	7.170	
20	26.692	13.960	32.811	20.638	26.334	12.937	?	21.542	6.426	22.624	47.797	7.265	
21	21.443	13.530	29.896	21.161	22.247	9.406	?	20.713	6.167	17.617	39.314	6.674	
22	17.941	13.479	28.349	21.588	19.767	8.579	?	15.517	5.955	14.654	26.248	7.486	
23	24.752	14.790	24.554	18.953	18.166	19.102	?	11.056	6.211	12.879	21.099	19.623	
24	111.157	13.847	24.122	17.798	16.950	12.925	?	8.835	5.693	11.608	30.993	21.746	
25	56.451	17.164	29.271	22.953	23.083	9.591	?	7.508	5.650	10.516	23.088	13.752	
26	30.884	41.935	33.048	41.599	23.597	8.719	8.821	6.804	5.755	9.542	17.245	10.922	
27	24.626	51.286	29.118	33.720	21.680	8.241	7.762	6.259	8.165	8.888	20.993	9.592	
28	36.743	32.404	29.337	24.239	28.289	8.004	6.608	5.738	16.309	8.507	31.980	8.628	
29	50.438	24.987	44.391	24.217	19.831	7.621	6.123		9.860	11.711	20.335	8.016	
30	39.760	21.948	36.397	23.341	17.360	7.540	5.702		9.656	58.193	16.215	7.579	
31	45.134	19.538		20.511		7.219	5.620		8.139		15.187		
Min	12.308	13.479	17.769	17.798	16.950	7.219	5.620	5.639	4.495	6.054	10.050	6.674	4.495
Mean	29.371	28.427	33.555	33.183	34.744	12.502	8.350	15.914	10.266	42.183	33.832	9.984	24.724
Max	111.157	80.929	86.432	68.923	91.870	20.460	16.311	92.803	52.570	219.793	159.851	21.746	219.793

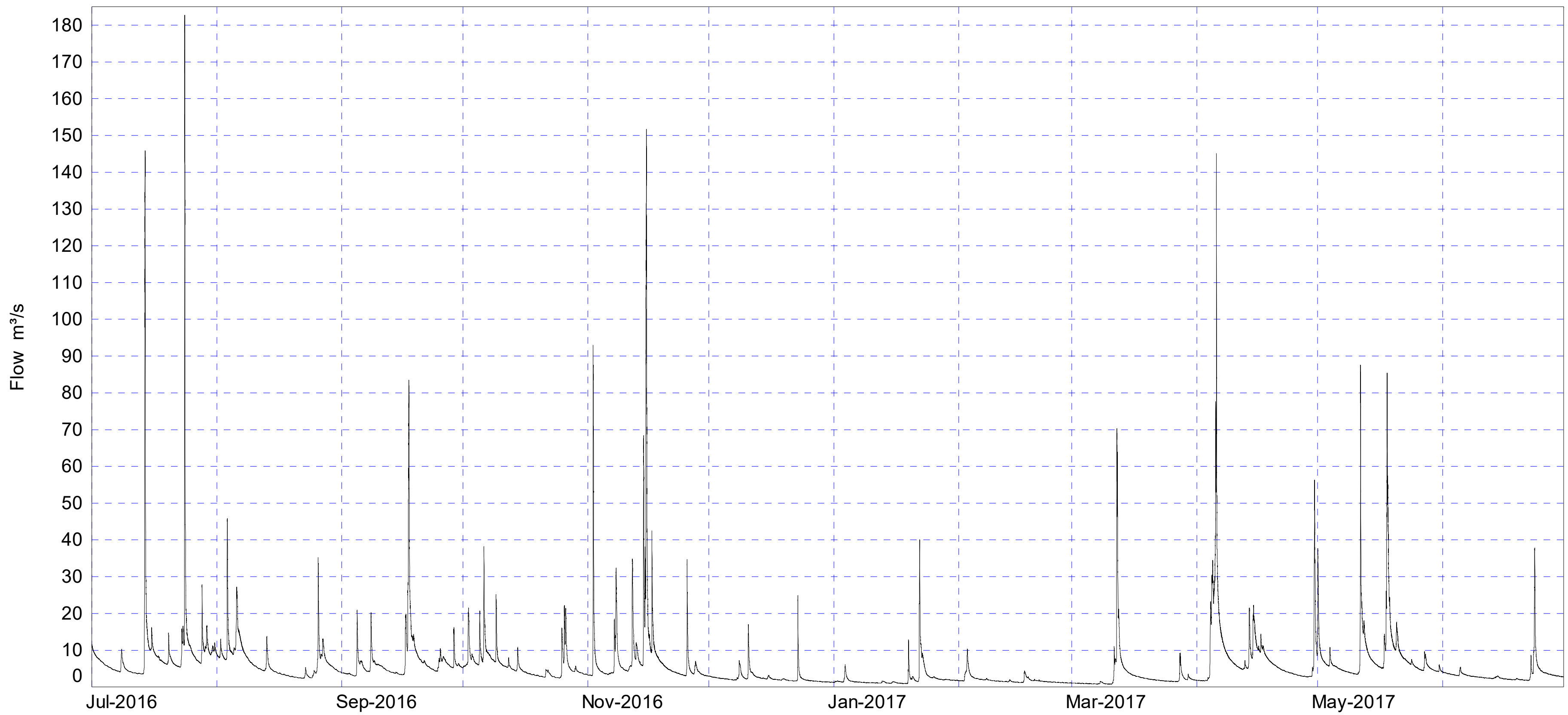


Flow in the Mangaehu River from July 2016 to June 2017

Source is R:\ARCHIVES\HYDRO-ARCHIVES.HTS
Flow (m³/sec) at Mangaehu at Bridge
From 1-Jul-2016 00:00:00 to 30-Jun-2017 24:00:00
24 hour periods beginning at midnight each day.

Daily means Years 2016-2017 Flow(m³/sec) at Mangaehu at Bridge

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
1	14.218	27.608	10.034	23.659	8.262	14.677	5.216	4.704	6.408	5.689	31.072	10.317	
2	10.647	34.450	9.670	19.059	12.781	11.505	7.098	10.898	5.318	5.179	15.841	9.339	
3	9.101	29.520	12.295	23.536	14.343	9.409	9.927	36.883	4.997	5.918	11.920	8.704	
4	8.047	65.887	12.813	27.692	11.011	8.416	16.262	17.037	4.861	89.433	15.914	8.081	
5	7.289	52.095	35.751	27.209	9.096	8.086	9.303	9.479	4.785	133.843	14.138	9.123	
6	6.727	78.341	27.781	50.008	10.046	7.566	6.333	7.378	4.610	62.811	10.717	8.738	
7	6.127	36.854	17.194	51.670	15.110	7.107	5.662	6.665	4.489	26.705	9.432	7.618	
8	12.606	22.208	29.761	32.683	36.136	8.523	5.251	8.848	9.396	17.100	8.706	7.056	
9	12.061	17.284	31.895	38.540	18.591	9.447	4.998	8.561	9.605	12.956	8.177	6.673	
10	7.319	14.563	20.773	28.322	12.979	8.061	4.937	6.264	5.592	10.758	7.857	6.561	
11	6.052	12.776	16.719	18.842	15.902	8.892	4.777	5.860	7.209	9.402	13.116	6.350	
12	5.481	11.493	13.770	19.926	35.397	9.363	4.686	5.257	21.984	8.965	69.939	6.181	
13	5.172	16.629	12.185	21.927	32.252	7.410	11.526	5.616	25.873	11.761	38.116	6.312	
14	13.822	19.507	14.428	18.791	20.882	8.381	9.082	9.412	12.141	42.272	18.853	11.460	
15	19.496	13.325	18.452	25.512	37.714	11.304	5.964	6.869	8.708	56.075	14.527	8.763	
16	23.703	11.451	17.804	18.441	54.441	13.674	9.560	5.399	7.044	48.122	12.355	7.150	
17	13.688	10.290	52.163	14.936	53.279	9.141	6.873	10.682	6.200	88.439	14.032	6.821	
18	11.600	9.594	61.037	12.616	45.296	6.994	5.454	70.816	5.773	44.988	94.789	6.176	
19	8.997	8.903	29.375	11.357	24.533	8.473	6.317	34.942	5.468	21.934	60.301	6.211	
20	14.303	8.502	19.483	10.617	18.235	12.466	8.351	18.290	5.092	16.358	28.884	6.443	
21	11.121	8.069	17.424	10.490	14.572	7.712	6.712	17.884	4.990	13.126	25.108	5.896	
22	7.943	7.762	16.863	10.458	12.343	6.644	8.287	14.014	4.900	11.061	17.493	6.010	
23	8.783	7.949	13.669	8.882	10.967	15.547	16.449	10.299	5.324	9.883	14.573	9.111	
24	90.464	7.766	13.593	8.035	9.987	11.974	9.994	8.381	4.886	9.054	21.979	14.055	
25	53.595	9.658	15.265	9.385	10.436	7.816	7.200	7.227	4.920	8.367	17.036	10.092	
26	24.106	27.498	19.332	20.740	15.738	6.818	7.294	6.561	5.089	7.728	13.153	8.183	
27	18.182	41.915	16.656	20.626	13.820	6.284	6.516	6.047	6.241	7.286	14.725	7.260	
28	27.584	23.058	15.813	12.364	21.570	6.083	5.419	5.570	12.456	7.044	23.076	6.547	
29	44.604	15.932	32.219	12.272	13.170	5.679	4.905		8.315	9.495	15.492	6.124	
30	33.958	13.451	24.462	12.095	10.807	5.606	4.573		8.088	30.993	12.606	5.852	
31	39.937	11.338		9.543		5.278	4.572		7.074		11.389		
Min	5.172	7.762	9.670	8.035	8.262	5.278	4.572	4.704	4.489	5.179	7.857	5.852	4.489
Mean	18.604	21.796	21.623	20.330	20.657	8.850	7.403	13.066	7.672	27.758	22.107	7.773	16.465
Max	90.464	78.341	61.037	51.670	54.441	15.547	16.449	70.816	25.873	133.843	94.789	14.055	133.843

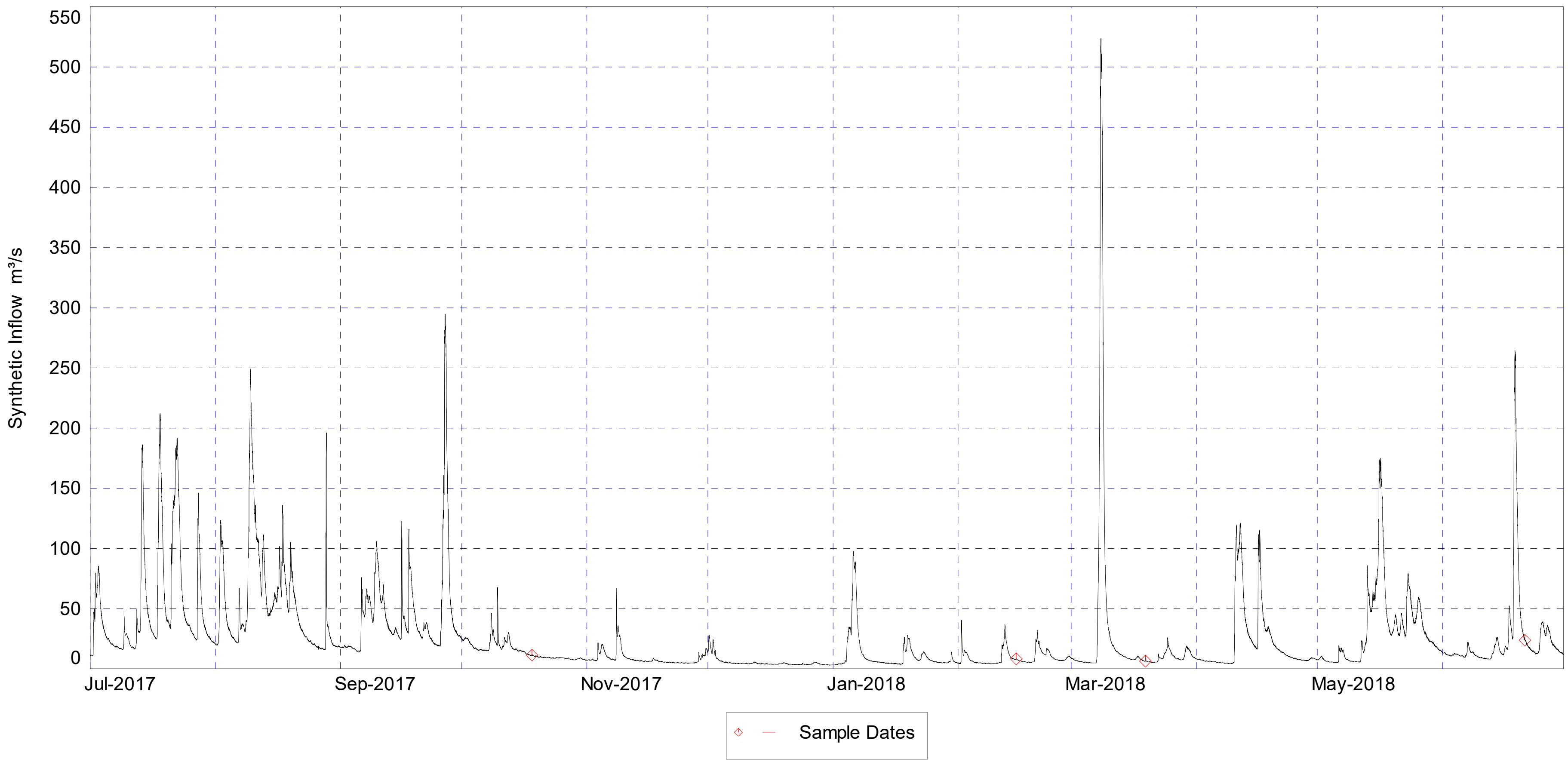


Flow in the Patea River at Skinner Road from July 2016 to June 2017

Source is R:\ARCHIVES\HYDRO-ARCHIVES.HTS
Flow (m³/sec) at Patea at Skinner Rd
From 1-Jul-2016 00:00:00 to 30-Jun-2017 24:00:00
24 hour periods beginning at midnight each day.

Daily means   Years 2016-2017   Flow(m³/sec) at Patea at Skinner Rd

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
1	9.661	8.873	3.780	5.705	3.212	2.851	1.441	1.712	1.049	1.781	15.266	3.907	
2	7.875	8.805	3.604	11.221	19.242	2.626	1.475	3.034	1.006	1.703	7.094	3.606	
3	6.848	14.702	3.299	7.833	5.418	2.425	2.671	5.627	0.963	1.943	6.136	3.371	
4	5.894	9.905	6.512	6.298	4.129	2.276	2.378	2.712	0.932	17.168	6.960	3.163	
5	5.281	13.178	7.024	9.833	3.614	2.169	1.557	2.277	0.892	44.978	5.562	4.114	
6	4.679	15.847	5.287	15.127	3.666	2.023	1.383	2.069	0.852	23.228	4.897	3.421	
7	4.323	10.360	4.302	8.896	8.983	1.953	1.298	2.024	0.852	12.401	4.429	3.072	
8	6.909	8.103	9.796	7.359	12.217	4.216	1.219	1.922	1.250	9.077	4.088	2.889	
9	4.871	6.625	6.322	10.453	5.272	2.918	1.165	1.728	0.874	7.301	3.768	2.750	
10	4.174	5.710	5.863	6.344	4.491	5.034	1.152	1.624	0.819	6.162	3.519	2.637	
11	3.852	5.021	5.100	5.604	5.612	4.599	1.108	1.554	4.717	5.336	19.747	2.492	
12	3.675	4.551	4.398	5.860	14.468	3.019	1.104	1.475	25.697	5.126	15.298	2.388	
13	3.757	7.616	3.967	4.737	8.644	2.562	1.405	1.625	6.818	5.890	9.531	2.364	
14	38.316	4.920	3.801	5.980	15.414	2.359	1.061	1.414	4.565	11.739	7.303	2.797	
15	11.413	4.143	3.422	4.811	49.633	2.517	1.231	1.290	3.659	15.344	6.156	2.401	
16	9.678	3.703	7.831	4.035	14.410	2.356	1.190	1.229	3.140	10.576	5.370	2.214	
17	8.014	3.394	31.425	3.608	12.514	2.060	1.015	3.003	2.810	10.371	9.615	2.082	
18	6.951	3.112	14.482	3.329	7.848	1.936	0.954	2.218	2.533	7.984	37.430	1.990	
19	6.451	2.854	9.645	3.111	6.374	2.119	3.636	1.793	2.298	6.708	13.306	2.149	
20	8.750	2.677	7.379	2.866	5.256	1.861	2.384	1.765	2.105	5.851	12.577	1.975	
21	6.206	2.486	6.605	3.536	4.560	1.728	1.644	1.599	1.954	5.087	9.468	1.883	
22	5.577	2.686	5.521	3.760	4.077	1.698	13.472	1.478	1.841	4.512	7.710	2.895	
23	12.456	3.390	4.810	2.802	3.667	5.609	5.866	1.388	1.719	4.084	6.702	11.677	
24	36.257	2.715	4.578	2.537	3.308	2.133	3.008	1.325	1.607	3.753	6.404	7.082	
25	10.612	4.389	7.779	6.326	8.863	1.828	2.604	1.236	1.551	3.414	5.346	4.419	
26	8.231	13.008	7.486	13.041	4.650	1.688	2.359	1.198	1.505	3.123	4.714	3.819	
27	6.905	9.826	6.046	5.393	4.857	1.589	2.079	1.145	3.106	2.935	6.587	3.470	
28	11.807	6.678	7.373	4.484	4.280	1.501	2.003	1.082	3.651	2.805	5.672	3.207	
29	11.936	5.664	6.340	4.416	3.382	1.413	1.976		2.266	3.597	4.759	3.006	
30	9.477	4.772	5.582	3.784	3.052	1.384	1.868		2.333	19.778	4.332	2.801	
31	10.189	4.127		3.452		1.287	1.792		1.919		4.699		
Min	3.675	2.486	3.299	2.537	3.052	1.287	0.954	1.082	0.819	1.703	3.519	1.883	0.819
Mean	9.388	6.576	6.979	6.017	8.504	2.443	2.242	1.877	2.945	8.792	8.530	3.335	5.653
Max	38.316	15.847	31.425	15.127	49.633	5.609	13.472	5.627	25.697	44.978	37.430	11.677	49.633

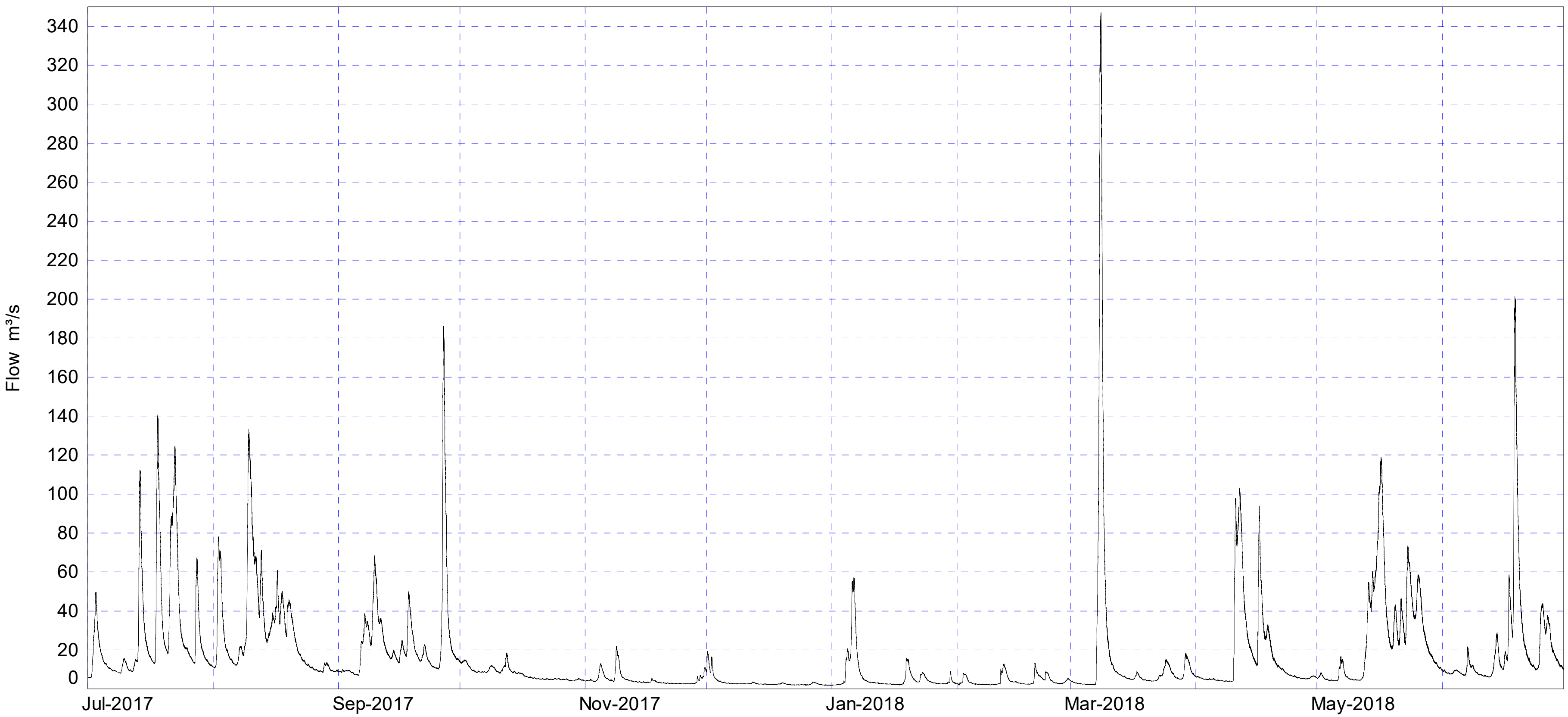


Synthetic inflow at Lake Rotorangi for the period 1 July 2017 to 30 June 2018

Source is R:\PROCESSING-FILE\WATER TAKES & DISCHARGES.hts
Synthetic Inflow (m3/sec) at Patea Dam
From 1-Jul-2017 00:00:00 to 30-Jun-2018 24:00:00
24 hour periods beginning at midnight each day.

Daily means   Years 2017-2018   Synthetic Inflow(m3/sec) at Patea Dam

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
1	17.589	23.182	18.071	24.617	7.336	20.098	3.402	11.576	8.150	8.028	8.616	13.018	
2	63.194	101.675	18.370	24.616	7.539	15.901	4.104	13.959	6.672	7.163	8.302	11.452	
3	60.184	56.672	18.408	19.797	10.361	8.023	4.776	10.514	6.001	6.468	6.245	11.382	
4	32.163	32.015	16.282	16.775	16.321	6.256	18.609	6.401	5.498	6.324	5.645	12.204	
5	24.336	25.332	14.761	15.822	14.271	5.401	44.491	5.340	5.165	6.135	5.423	10.920	
6	20.352	29.262	48.308	15.545	9.180	4.946	78.906	4.973	4.942	5.426	13.190	10.445	
7	18.426	36.924	57.164	16.142	7.731	4.653	25.784	4.699	47.783	5.032	12.985	17.340	
8	16.878	37.018	51.203	32.099	26.862	4.504	11.390	4.559	400.740	4.750	7.521	13.361	
9	27.080	169.908	71.291	25.502	20.387	4.521	7.829	4.350	95.170	4.593	6.334	10.644	
10	24.099	153.454	78.292	20.403	10.129	4.464	6.553	4.648	29.360	48.973	5.912	9.350	
11	17.792	104.732	57.929	21.175	8.430	4.465	6.038	8.460	18.483	103.821	8.968	8.727	
12	28.346	82.775	39.567	25.528	7.459	5.247	5.571	24.870	13.914	78.616	17.750	8.263	
13	86.422	67.233	30.672	18.116	6.918	4.523	5.077	14.394	11.483	35.627	52.853	13.682	
14	99.272	46.296	31.233	15.948	6.620	4.359	4.755	8.682	9.661	24.693	53.168	22.723	
15	43.283	55.826	26.885	15.022	6.371	4.160	4.568	7.803	8.294	18.854	68.770	13.769	
16	30.111	69.219	50.391	13.952	6.229	3.945	4.358	6.588	7.730	76.502	146.982	15.785	
17	52.796	87.244	40.818	11.989	7.510	3.881	4.062	5.839	9.579	49.084	94.242	34.211	
18	166.301	68.386	75.573	11.160	6.893	4.026	14.469	5.504	7.600	32.780	38.860	103.520	
19	60.561	71.468	44.178	10.388	5.927	4.635	22.203	5.904	6.341	27.405	30.157	148.808	
20	37.769	64.615	30.111	9.862	5.593	4.402	15.618	22.221	5.772	19.215	38.691	41.826	
21	118.350	42.755	30.645	9.496	5.356	3.753	8.863	16.737	5.449	15.689	34.544	23.792	
22	170.949	31.705	34.208	9.379	5.186	3.560	8.040	12.899	7.811	13.441	32.325	17.614	
23	87.200	26.231	24.609	8.999	5.060	3.549	12.913	14.543	9.018	11.059	65.654	14.490	
24	43.217	22.575	20.550	9.108	4.978	3.885	9.073	9.250	15.592	9.658	48.266	13.386	
25	35.520	20.046	22.180	9.274	4.898	3.687	6.677	7.529	15.982	8.706	44.863	33.491	
26	28.633	17.987	149.899	8.873	4.919	3.834	5.780	6.939	10.262	7.787	51.146	31.570	
27	65.072	16.693	167.278	8.467	5.006	5.247	5.247	7.769	8.190	7.224	31.736	30.043	
28	67.906	49.325	49.125	7.616	7.320	4.434	5.055	10.087	7.871	7.058	24.666	19.852	
29	33.887	26.390	31.696	7.988	9.961	3.596	5.416		15.947	8.731	21.742	16.025	
30	26.028	19.373	27.002	8.640	13.834	3.349	8.423		14.145	8.205	18.067	?	
31	22.122	18.500		7.680		3.247	5.377		9.435		15.057		
Min	16.878	16.693	14.761	7.616	4.898	3.247	3.402	4.350	4.942	4.593	5.423	8.263	3.247
Mean	52.446	54.026	45.890	14.838	8.819	5.308	12.046	9.537	26.711	22.235	32.861	25.231	25.968
Max	170.949	169.908	167.278	32.099	26.862	20.098	78.906	24.870	400.740	103.821	146.982	148.808	400.740

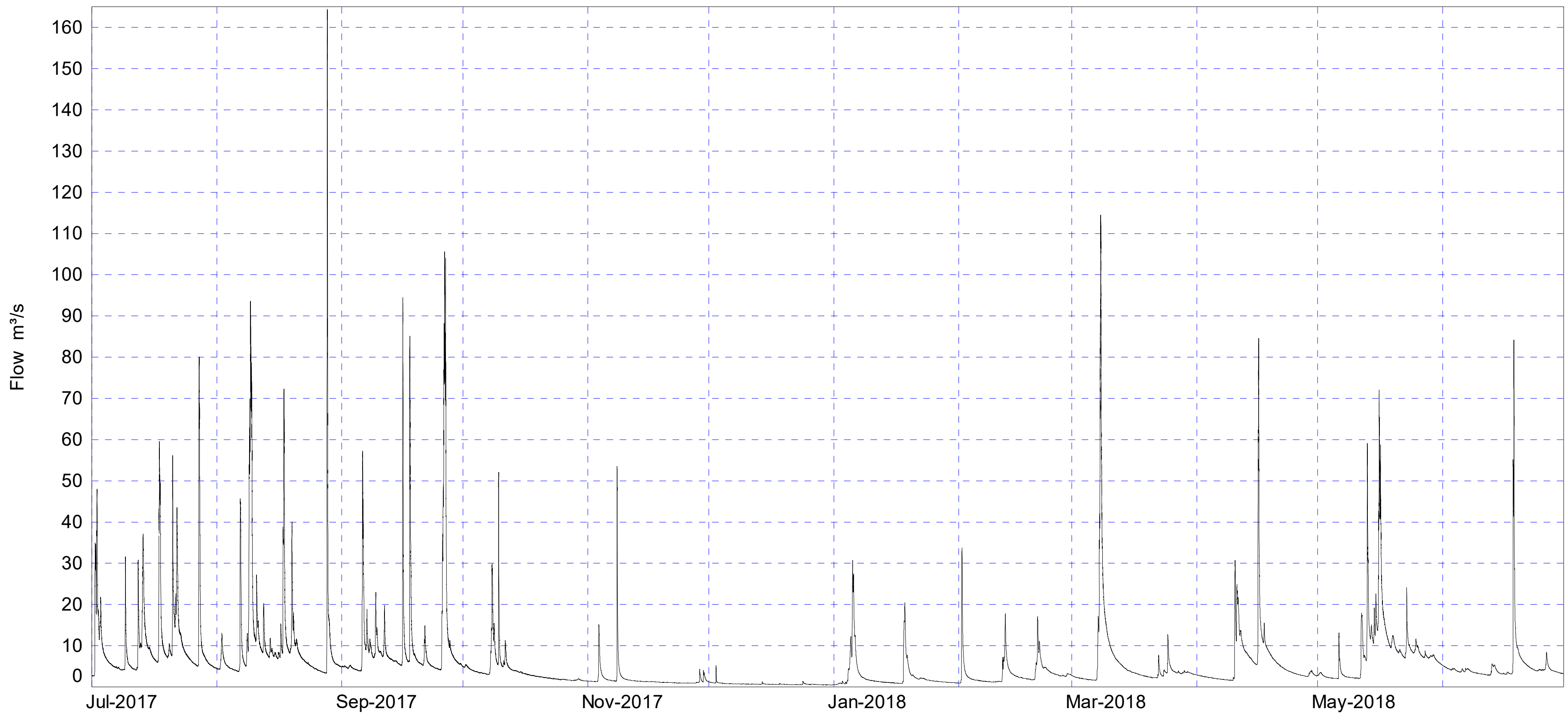


Flow in the Mangaehu River from July 2017 to June 2018

Source is R:\ARCHIVES\HYDRO-ARCHIVES.HTS
Flow (m^3/sec) at Mangaehu at Bridge
From 1-Jul-2017 00:00:00 to 30-Jun-2018 24:00:00
24 hour periods beginning at midnight each day.

Daily means Years 2017-2018 Flow(m^3/sec) at Mangaehu at Bridge

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
1	5.949	13.354	8.931	13.822	4.189	13.460	1.985	2.622	3.759	6.151	6.390	9.090	
2	27.281	66.207	9.290	14.083	4.366	10.257	2.255	5.595	2.970	5.456	6.472	8.020	
3	32.287	35.855	9.253	11.102	4.026	4.879	2.690	5.611	2.651	4.931	4.775	8.118	
4	17.069	19.253	8.177	9.242	8.957	3.752	11.504	3.106	2.431	4.958	4.367	9.398	
5	12.612	14.825	7.261	8.748	8.603	3.209	20.229	2.512	2.287	4.956	4.265	8.169	
6	10.433	12.613	17.057	8.702	5.218	2.916	48.272	2.375	2.196	4.371	9.274	7.436	
7	9.339	18.596	31.838	8.687	4.299	2.731	15.726	2.279	30.154	4.132	11.792	15.404	
8	8.570	19.650	29.618	10.885	11.793	2.639	6.389	2.237	259.177	3.991	6.073	11.150	
9	11.388	77.068	42.217	10.726	12.421	2.649	4.195	2.151	77.012	3.931	4.962	8.397	
10	12.976	97.533	49.121	8.636	5.670	2.625	3.454	2.298	22.183	40.356	4.629	7.181	
11	9.461	64.433	33.490	9.895	4.617	2.640	3.208	4.401	11.833	86.822	4.533	6.686	
12	11.993	50.195	22.541	14.613	4.018	3.198	2.974	10.696	8.470	71.993	8.914	6.306	
13	48.003	41.057	16.934	9.863	3.684	2.709	2.710	6.616	7.021	33.732	36.961	10.191	
14	60.222	26.046	17.697	8.535	3.533	2.481	2.543	3.780	6.049	21.223	48.552	22.842	
15	24.023	33.806	15.074	8.098	3.397	2.442	2.459	3.564	5.213	15.103	60.099	12.110	
16	16.224	42.740	20.330	7.574	3.322	2.316	2.357	2.924	5.062	49.003	100.899	14.905	
17	22.088	41.086	18.699	6.374	4.263	2.277	2.212	2.561	7.529	43.347	78.326	37.701	
18	106.292	40.043	40.804	5.917	3.866	2.354	2.707	2.438	5.662	28.435	33.044	76.966	
19	36.850	38.888	26.182	5.493	3.242	2.803	11.515	2.774	4.593	23.746	22.723	123.316	
20	20.339	36.466	17.156	5.216	3.021	2.665	8.829	9.415	4.263	14.631	36.044	41.804	
21	68.075	23.812	15.510	5.067	2.894	2.236	4.594	6.501	4.088	11.598	31.913	21.721	
22	105.012	17.323	19.812	5.069	2.798	2.082	4.169	5.605	4.861	9.978	30.434	14.685	
23	53.295	14.107	13.827	4.890	2.737	2.081	7.668	7.339	7.038	8.056	60.072	11.610	
24	24.641	12.079	11.309	5.044	2.704	2.120	5.138	4.009	12.474	6.987	47.276	10.831	
25	20.272	10.734	10.677	5.105	2.669	2.105	3.585	3.057	11.691	6.371	42.763	36.807	
26	16.105	9.658	58.475	4.820	2.685	2.244	3.035	2.814	7.477	5.722	50.940	32.897	
27	28.199	9.017	108.163	4.800	2.746	3.265	2.734	3.416	5.503	5.373	29.912	31.477	
28	40.574	11.287	28.877	4.261	3.872	2.725	2.667	4.775	5.290	5.241	20.710	19.045	
29	19.086	11.821	17.909	4.407	5.447	2.146	2.993		14.568	6.021	16.199	14.448	
30	14.424	9.256	15.165	4.986	8.496	1.980	5.191		12.431	6.310	12.934	11.398	
31	12.137	9.123		4.395		1.920	3.047		7.413		10.554		
Min	5.949	9.017	7.261	4.261	2.669	1.920	1.985	2.151	2.196	3.931	4.265	6.306	1.920
Mean	29.201	29.933	24.713	7.711	4.785	3.223	6.550	4.195	18.172	18.098	27.316	21.670	16.386
Max	106.292	97.533	108.163	14.613	12.421	13.460	48.272	10.696	259.177	86.822	100.899	123.316	259.177



Flow in the Patea River at Skinner Road from July 2017 to June 2018

Source is R:\ARCHIVES\HYDRO-ARCHIVES.HTS
Flow (m^3/sec) at Patea at Skinner Rd
From 1-Jul-2017 00:00:00 to 30-Jun-2018 24:00:00
24 hour periods beginning at midnight each day.

Daily means Years 2017-2018 Flow(m^3/sec) at Patea at Skinner Rd

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
1	9.970	4.624	4.972	5.060	1.409	1.116	0.576	7.828	2.577	2.811	3.218	4.945	
2	22.022	8.444	4.762	4.631	1.336	1.372	0.870	5.068	2.268	2.600	2.757	4.402	
3	12.575	5.264	4.789	4.020	4.807	1.031	0.954	2.318	2.072	2.414	2.332	4.319	
4	7.122	4.498	4.222	3.675	3.505	0.895	2.745	1.839	1.897	2.266	2.161	3.962	
5	5.772	4.090	4.243	3.438	1.943	0.822	15.954	1.652	1.776	2.087	2.061	3.840	
6	4.982	11.932	22.204	3.232	1.640	0.782	9.119	1.490	1.693	1.951	5.253	4.013	
7	4.609	8.743	11.264	4.095	1.483	0.751	3.094	1.370	13.148	1.832	2.791	4.199	
8	4.178	10.190	8.394	15.786	9.909	0.732	2.155	1.294	51.794	1.720	2.410	3.611	
9	10.067	56.685	12.165	10.464	2.479	0.740	1.750	1.220	15.656	1.645	2.261	3.362	
10	5.164	14.474	8.443	6.888	1.861	0.718	1.554	1.312	10.230	12.391	2.170	3.191	
11	4.322	12.242	10.372	7.028	1.647	0.708	1.397	2.360	7.668	17.005	5.822	3.021	
12	11.158	11.342	7.411	4.786	1.514	0.698	1.274	9.104	6.235	10.247	9.067	2.933	
13	19.497	8.082	6.555	4.068	1.433	0.651	1.159	4.422	5.206	8.094	21.458	4.983	
14	12.348	8.909	6.147	3.806	1.355	0.806	1.080	3.032	4.349	6.816	12.476	3.996	
15	8.729	7.666	5.496	3.535	1.313	0.666	1.019	2.535	3.823	5.695	15.627	3.239	
16	6.812	8.808	20.394	3.195	1.294	0.638	0.957	2.250	3.454	29.660	40.006	3.197	
17	22.825	26.923	15.828	2.930	1.265	0.628	0.877	2.040	3.117	12.104	16.579	3.347	
18	13.892	10.355	14.922	2.751	1.176	0.671	10.103	1.890	2.817	9.411	11.382	23.057	
19	7.661	15.826	6.869	2.566	1.111	0.653	5.415	1.953	2.581	7.593	11.025	10.210	
20	9.181	11.648	5.721	2.432	1.097	0.600	2.821	8.656	2.371	6.309	9.278	6.968	
21	22.105	8.167	8.607	2.271	1.060	0.565	2.151	6.573	2.265	5.362	8.436	5.691	
22	21.521	6.607	6.017	2.136	1.020	0.585	2.058	4.617	3.801	4.602	7.628	4.856	
23	10.414	5.733	4.980	2.000	0.980	0.574	1.957	3.792	3.063	4.012	12.388	4.259	
24	7.850	4.994	4.502	1.900	0.954	0.845	1.660	3.269	5.059	3.606	8.621	3.995	
25	6.546	4.402	8.400	1.830	0.941	0.664	1.489	2.928	5.325	3.243	9.891	4.134	
26	5.603	3.928	63.297	1.785	0.945	0.640	1.381	2.729	3.735	2.950	8.086	5.446	
27	24.575	3.548	12.040	1.659	0.951	0.617	1.281	2.753	3.501	2.728	7.492	4.717	
28	9.102	31.014	7.747	1.609	1.750	0.551	1.202	3.072	3.450	2.735	7.227	3.909	
29	6.449	8.404	6.195	1.822	2.098	0.533	1.120		3.606	3.582	7.561	3.598	
30	5.340	5.683	5.445	1.626	1.637	0.527	1.052		3.368	2.845	6.519	3.325	
31	4.706	5.083		1.467		0.507	0.991		3.063		5.615		
Min	4.178	3.548	4.222	1.467	0.941	0.507	0.576	1.220	1.693	1.645	2.061	2.933	0.507
Mean	10.552	10.913	10.413	3.822	1.864	0.719	2.620	3.335	5.967	6.010	8.697	4.957	5.843
Max	24.575	56.685	63.297	15.786	9.909	1.372	15.954	9.104	51.794	29.660	40.006	23.057	63.297

Appendix II

TRC Lake Rotorangi water quality trend analysis 1990-2017

Memorandum

To	J Kitto, Science Advisor
From	J Kitto, Science Advisor
Document	#2226737
Date	20/03/2019

Lake Rotorangi trend analysis January 1990 to December 2017

Introduction

A trend analysis of Lake Rotorangi monitoring data from 1990 to 2017 has been undertaken to update analysis conducted by Burns (2006) for data from 1990-2006. This memo provides very little interpretation of the trend analysis, but reproduces analyses provided in the previous report by Burns (2006).

Methods of analysis

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

Results and discussion

Table 1 summarises the results of the trend analysis of parameters for each individual site (L2 and L3) as well as both sites combined in Appendix 1.

Table 3 provides the *p* and R values for these trends.

This trend analysis indicates that, while many of the parameters are not significantly changing over time, there is very significant ($p<0.01$) deterioration in nitrate nitrogen at both sites individually and in combination; and significant deterioration ($p<0.05$) in chlorophyll a at site L3 and very significant deterioration in chlorophyll when the sites are considered together. The Percent Annual Change (PAC) was calculated for those trends which were significant (PAC=slope/period average*100) and indicated that, when data from sites L2 and L3 are combined, nitrate nitrogen is increasing by 1.7% per year (or 6.7 $mgN/m^3/y$) and chlorophyll *a* is increasing by 1.9% per year (0.06 $mg/m^3/y$).

There is also a significant increasing trend in total phosphorus when data from both sites are combined, but not when they are considered individually. The PAC was calculated and indicated that, when data from sites L2 and L3 are combined, total phosphorus is increasing by 2.5% per year (or 0.72 $mgP/m^3/y$).

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 2017

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

Key:

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

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

😐 **no statistically significant change**

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

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

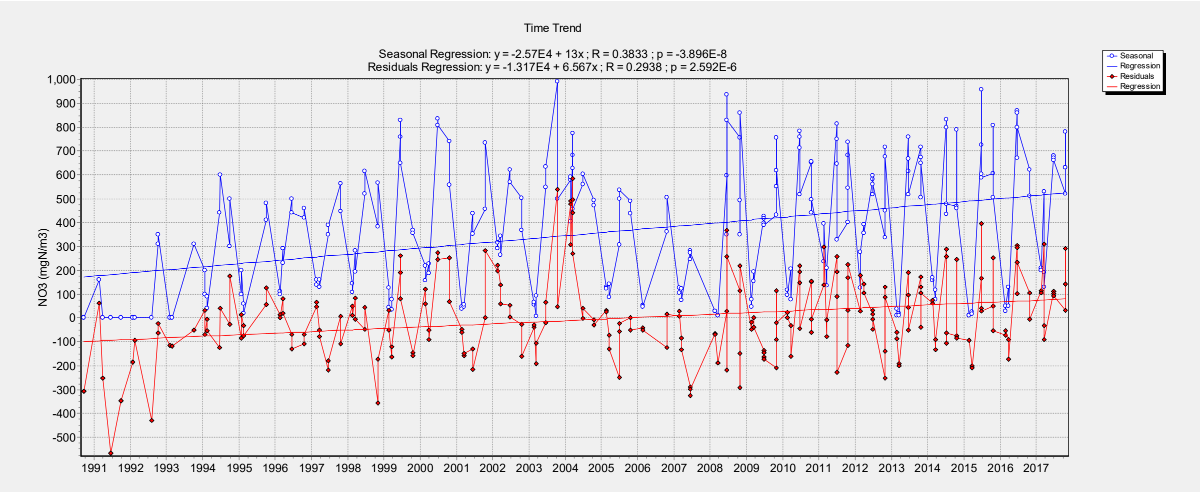


Figure 1: Nitrate nitrogen (NO3) trend line for sites L2 and L3 combined

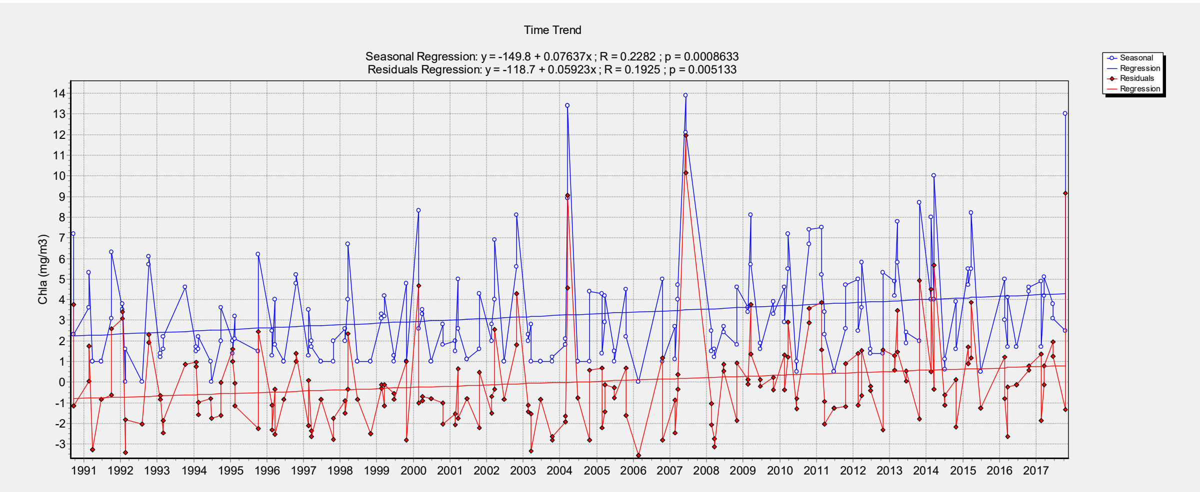


Figure 2: Chlorophyll a trend line for sites L2 and L3 combined

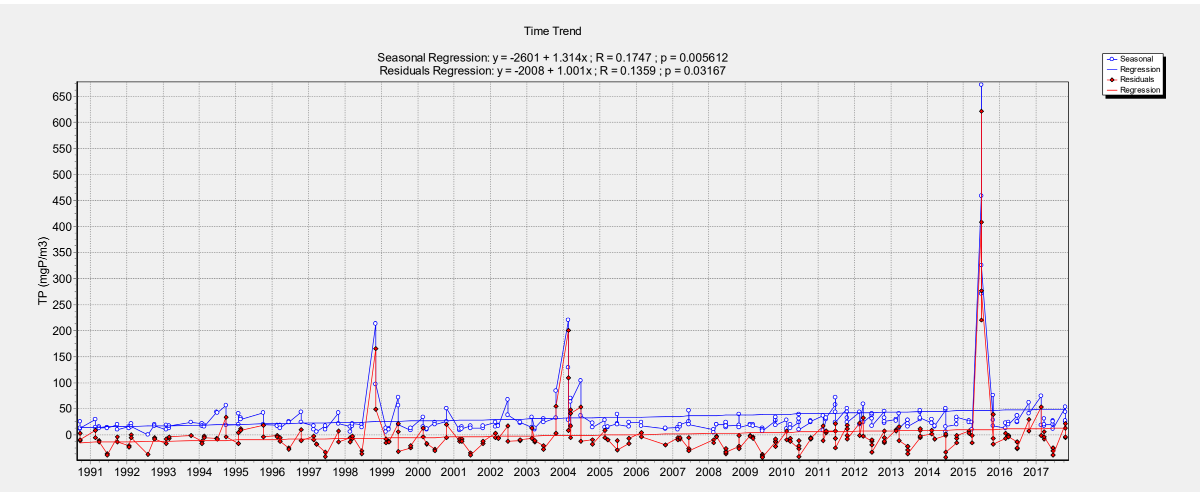


Figure 3: Total phosphorus trend line for sites L2 and L3 combined

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 1990-2017 period is 4.19 (±0.06) (Table 2 in Appendix 2). This indicates that the lake is eutrophic as per the following table (reproduced from Burns (2006)). However, when the individual key variables are compared with the trophic levels, chlorophyll *a* indicates that the lake is in a mesotrophic state, secchi depth indicates between mesotrophic and eutrophic states, and nutrients indicate a eutrophic state (see highlighted areas in Table 2).

When the sites are looked at individually the TLI of L2 continues to be slightly eutrophic; however L3 is within the mesotrophic boundary. Therefore site L2 continues to be more eutrophic at a TLI of 4.27 (possibly as a result of this site's proximity to the upper catchment) due to the higher total phosphorus and nitrogen levels 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 (3.89) indicated mesotrophic conditions in the 2017 year of monitoring.

The TLI is not changing significantly over time, according to the criterion that the trend is not significant at $p<0.05$, though the p-value for L2 and L3 combined, at 0.053, was only just outside this criterion. However in Burns' (2006) report, he notes that while there are no 'significant' trends in the trophic level or the average concentrations of the key variables (Chl *a*, Secchi, TP, TN), there are some insignificant increases in these variables; and coupled with a significant trend for NO_3, suggests that the trophic level is increasing, albeit at a very small rate of change (0.01 ±0.01 units per year), which he notes is not a cause for major concern. The current trend analysis continues to support this conclusion.

Table 2 Values of key variables that define the boundaries of different Trophic Levels (highlighted areas relate to the status of Lake Rotorangi using 1990-2017 data)

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

Hypolimnetic Volumetric Oxygen Depletion (HVOD) has been calculated for sites L2 and L3 using the 'Lakewatch' programme. The hypolimnion depths have been fitted to dissolved oxygen profiles for each year of analysis in the summer monitoring months of February and March; these values are based on recommendations by the Job Manager from past assessments of the stratification depth profiles. The HVOD *p* values indicate that there has been no significant change over the 1990-2017 period. Furthermore the HVOD parameter has been the subject of discussion at a national level and it has not been recommended for annual use in future national monitoring and reporting (NIWA, 2011). While TRC currently provides a yearly HVOD summary, on the basis of work currently being undertaken by NIWA and MfE, it may not be applicable for future HVOD analysis of Lake Rotorangi data. There have also been discrepancies over HVOD data currently stored in Lakewatch due to some difficulties with using the software in the 2013-2015 analysis; interpretation of these data should be viewed with caution. TRC will continue to be updated with national monitoring protocols and follow any guidance and instruction where necessary when monitoring and reporting on Lake Rotorangi.

Table 3 *p* and R values for trend analysis of 1990-2017 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*	0.06	0.19	0.04	0.20	0.005	0.19
DO	0.85	0.02	0.17	-0.13	0.40	-0.06
EC	0.32	0.08	0.78	0.02	0.36	0.05
Secchi Depth	0.67	0.04	0.29	-0.10	0.60	-0.04
TSS	0.13	0.13	0.19	0.10	0.14	0.08
Temperature	0.74	0.03	0.53	-0.06	0.77	-0.02
DRP	0.24	0.11	0.84	-0.018	0.49	0.04
NH_4	0.88	-0.014	0.73	0.03	0.92	0.006
NO_3	0.0006	0.30	0.0008	0.30	0.000002	0.29
TN	0.64	0.04	0.95	-0.006	0.79	-0.02
TP	0.13	0.13	0.12	0.14	0.03	0.14
HVOD	0.10	0.32	0.09	-0.33	0.54	-0.12
TLI	0.26	0.11	0.044	0.22	0.053	0.18

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, 2011: Lake Rotorangi trend analysis January 1990 to December 2010. TRC Internal Memo.

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

Connolly A, 2016: Lake Rotorangi trend analysis January 1990 to December 2015. TRC Internal Memo.

Giles K, 2010: Lake Rotorangi trend analysis January 1990 to December 2009. TRC Internal Memo

Hope K, 2009: Lake Rotorangi trend analysis January 1990 to December 2008. TRC Internal Memo

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

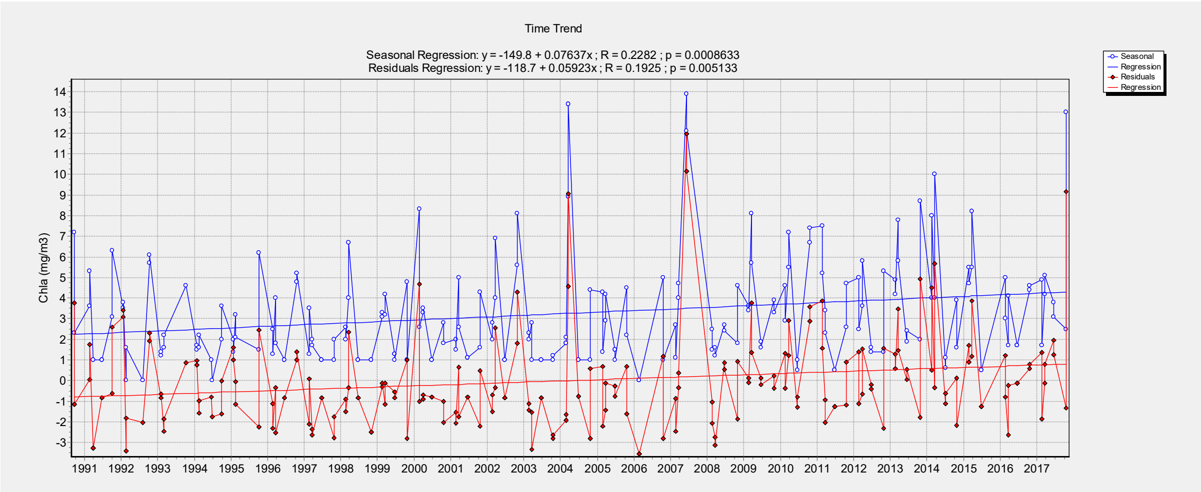
Hafiz F., 2014: Lake Rotorangi trend analysis January 1990 to December 2013. TRC Internal Memo

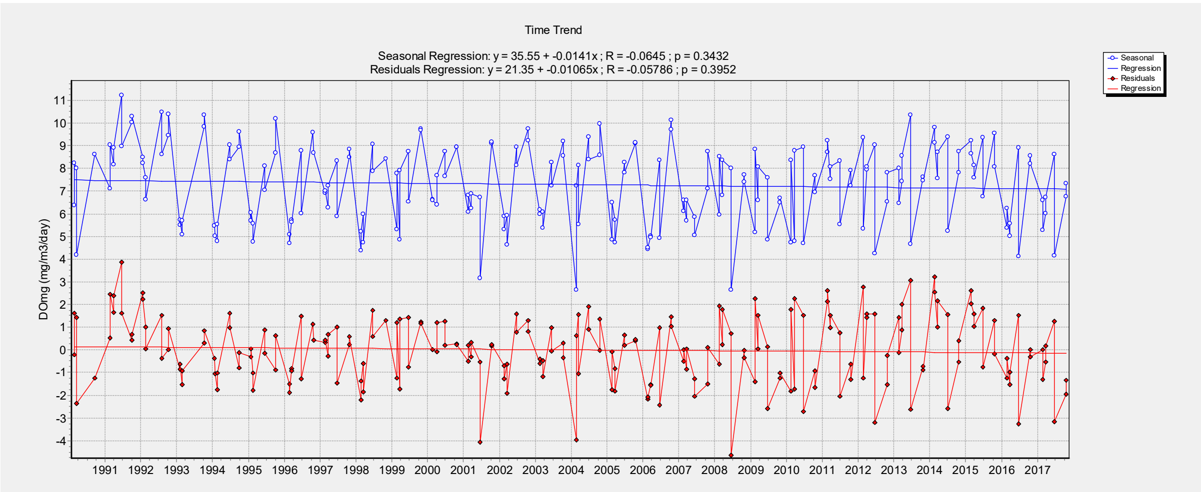
Hafiz F., 2015: Lake Rotorangi trend analysis January 1990 to December 2014. TRC Internal Memo

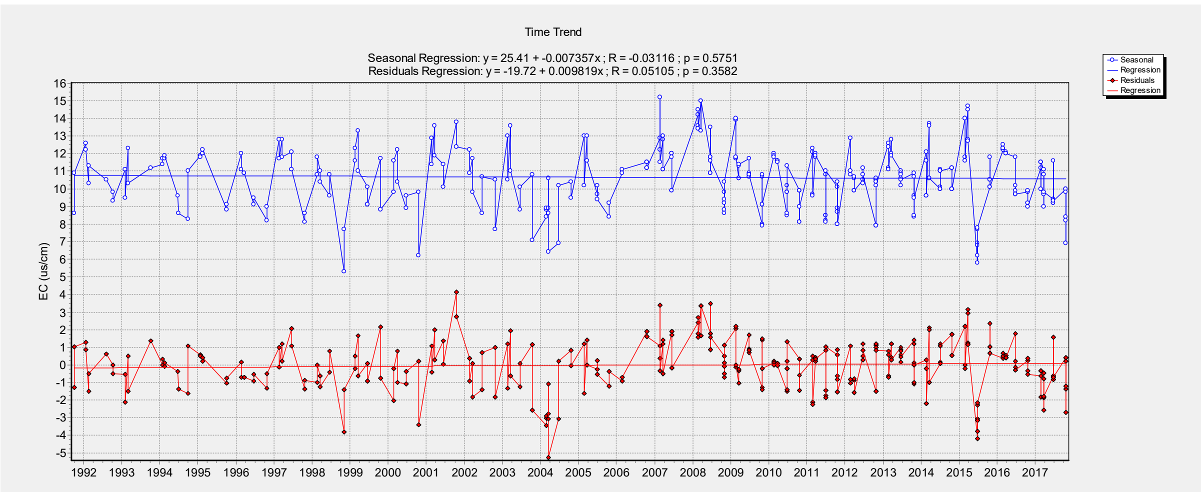
NIWA, 2011: Investigation of single indicators for water quality assessment and reporting-Prepared for the Ministry for the Environment. 108-113p.

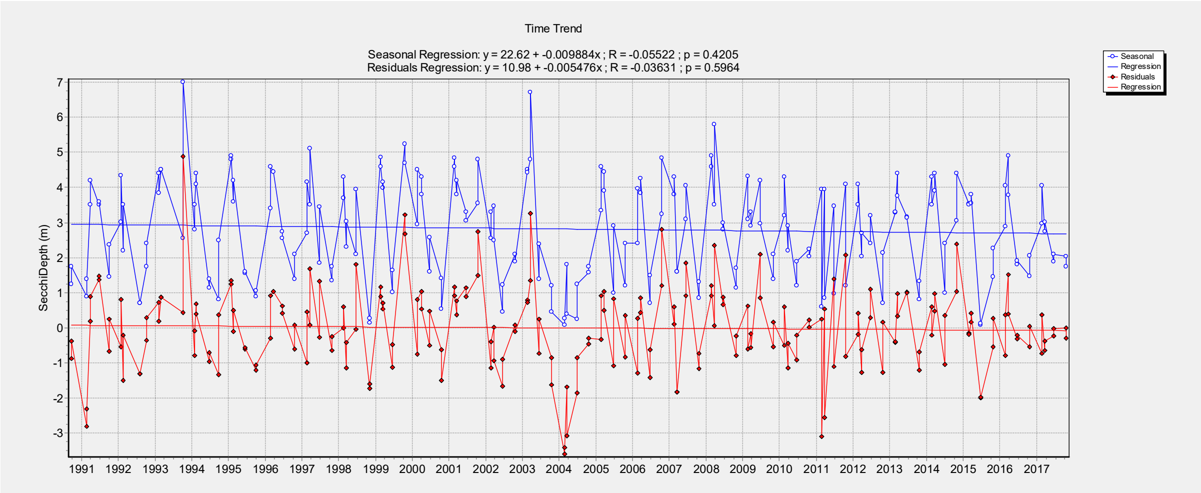
Appendix 2

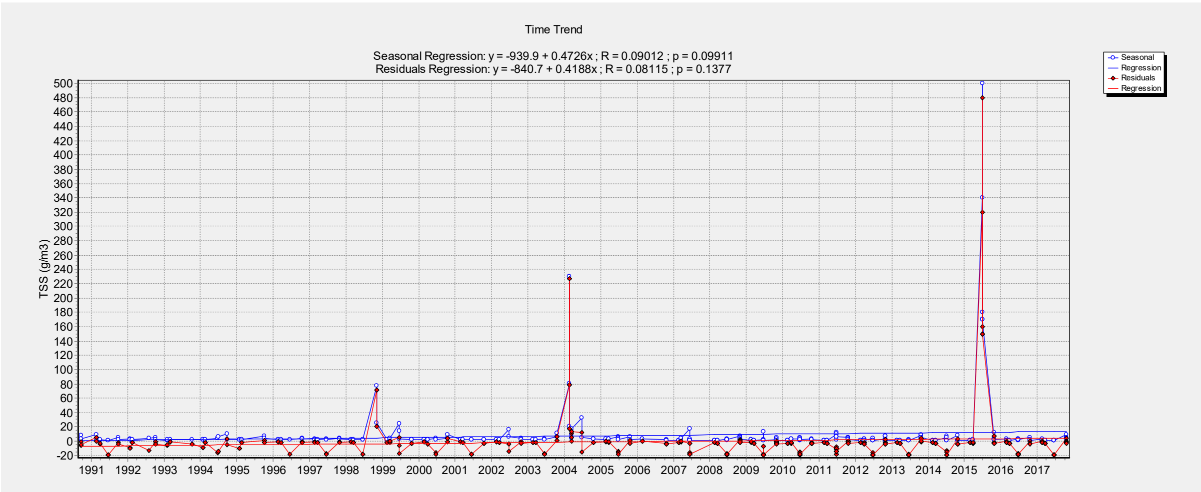
L2 and L3 combined – Physical parameters

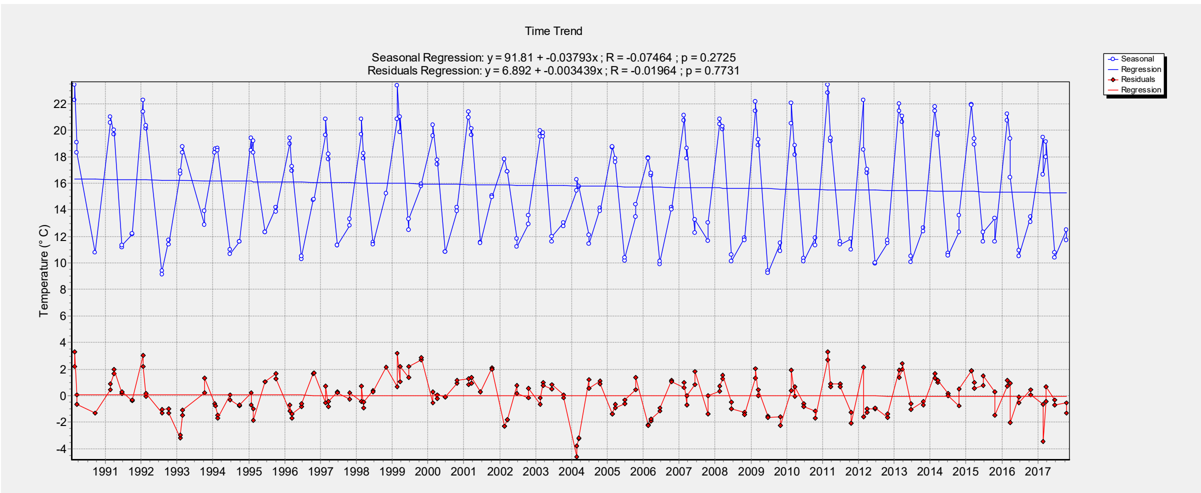




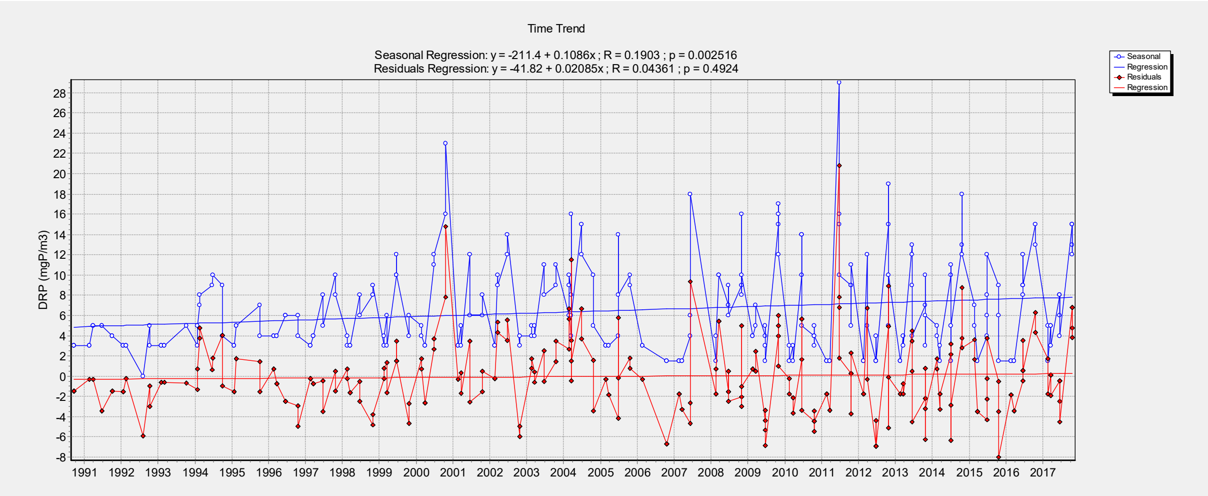


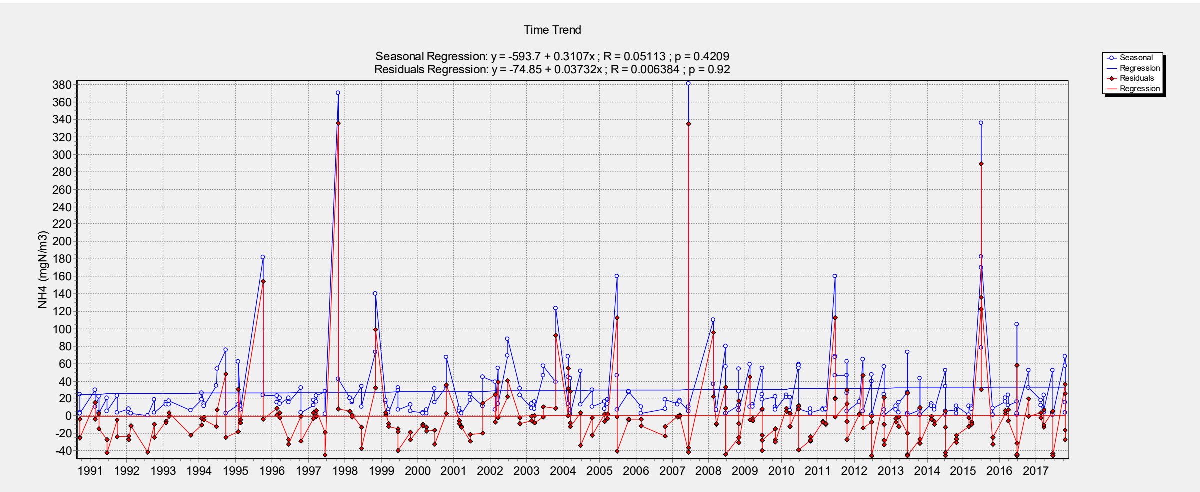

Time Trend
Seasonal Regression: y = 22.62 + -0.009884x ; R = -0.05522 ; p = 0.4205
Residuals Regression: y = 10.98 + -0.005476x ; R = -0.03631 ; p = 0.5964
SecchiDepth (m)
Seasonal
Regression
Residuals
Regression

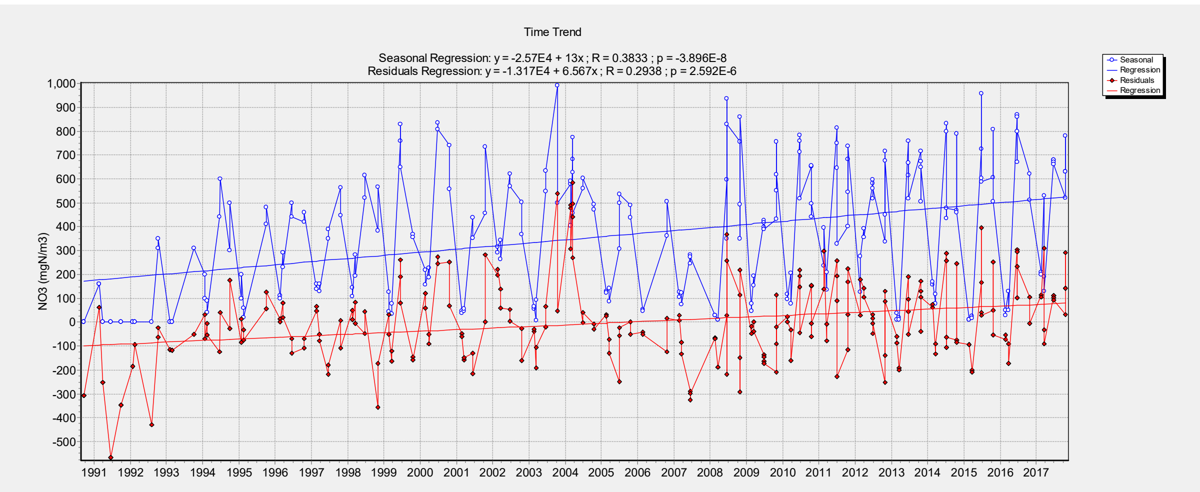

Time Trend
Seasonal Regression: y = -939.9 + 0.4726x ; R = 0.09012 ; p = 0.09911
Residuals Regression: y = -840.7 + 0.4188x ; R = 0.08115 ; p = 0.1377
TSS (g/m3)
Seasonal
Regression
Residuals
Regression

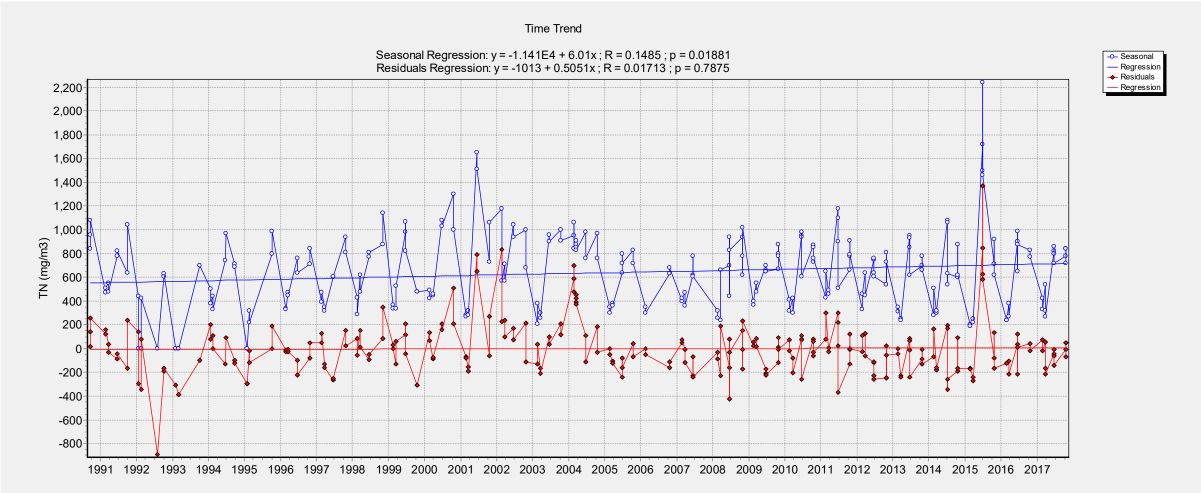

Time Trend
Seasonal Regression: y = 91.81 + -0.03793x ; R = -0.07464 ; p = 0.2725
Residuals Regression: y = 6.892 + -0.003439x ; R = -0.01964 ; p = 0.7731
Temperature (° C)
Seasonal
Regression
Residuals
Regression

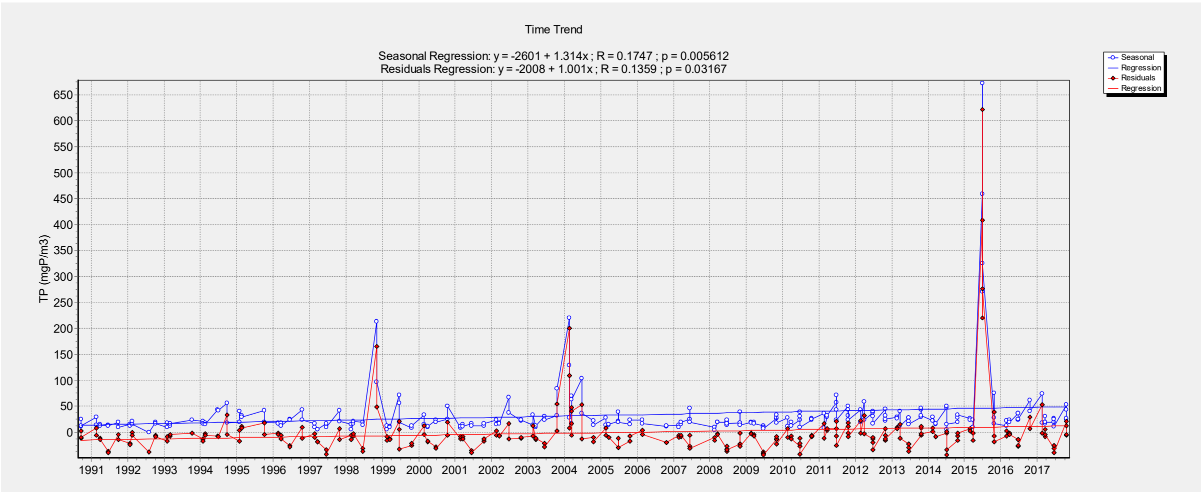
Nutrients- L2 and L3 combined








Time Trend
Seasonal Regression: y = -1.141E4 + 6.01x ; R = 0.1485 ; p = 0.01881
Residuals Regression: y = -1013 + 0.5051x ; R = 0.01713 ; p = 0.7875
TN (mg/m3)
Seasonal
Regression
Residuals
Regression


Time Trend
Seasonal Regression: y = -2601 + 1.314x ; R = 0.1747 ; p = 0.005612
Residuals Regression: y = -2008 + 1.001x ; R = 0.1359 ; p = 0.03167
TP (mgP/m3)
Seasonal
Regression
Residuals
Regression

HVOD Analysis

Lake: LAKE ROTORANGI

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

Date From: 01/01/1990 **Date To:** 31/12/2017

Analysis Period	Average	Observed DO	Observed Rate Corrected to 9.9 °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	10.9
01-Jan-1992 - 30-Mar-1992	9.85	10.1	10.2
01-Jan-1993 - 31-Mar-1993	9.4	-1.2	-1.2
01-Jan-1994 - 31-Mar-1994	8.55	18.8	20.6
01-Jan-1995 - 31-Mar-1995	11.1	40.2	37.0
01-Jan-1996 - 30-Mar-1996	8.94	27.3	29.2
01-Jan-1997 - 31-Mar-1997	8.66	14.5	15.9
01-Jan-1998 - 31-Mar-1998	8.31	5.6	6.3
01-Jan-1999 - 31-Mar-1999	13.32	13.7	10.9
01-Jan-2000 - 04-Apr-2000	10.12	5.6	5.5
01-Jan-2001 - 31-Mar-2001	11.08	16.4	15.2
01-Jan-2002 - 31-Mar-2002	8.73	8.9	9.7
01-Jan-2003 - 31-Mar-2003	9.66	-0.4	-0.4
01-Jan-2005 - 31-Mar-2005	8.94	37.0	39.6
01-Jan-2006 - 31-Mar-2006	9.42	19.1	19.8
01-Jan-2007 - 31-Mar-2007	10.19	5.1	5.0
01-Jan-2008 - 30-Mar-2008	9.49	4.8	4.9
01-Jan-2009 - 31-Mar-2009	10.06	10.2	10.1
01-Jan-2010 - 31-Mar-2010	8.97	-18.0	-19.2
01-Jan-2011 - 31-Mar-2011	10.25	24.0	23.4
01-Jan-2012 - 30-Mar-2012	9.25	-5.4	-5.6
01-Jan-2013 - 31-Mar-2013	9.93	13.0	13.0
01-Jan-2014 - 31-Mar-2014	10.96	8.9	8.3
01-Jan-2015 - 31-Mar-2015	9.63	2.2	2.2
01-Jan-2016 - 30-Mar-2016	10.32	22.8	22.2
01-Jan-2017 - 31-Mar-2017	10.66	13.9	13.2
Average	**9.92**	**11.5**	**11.4**

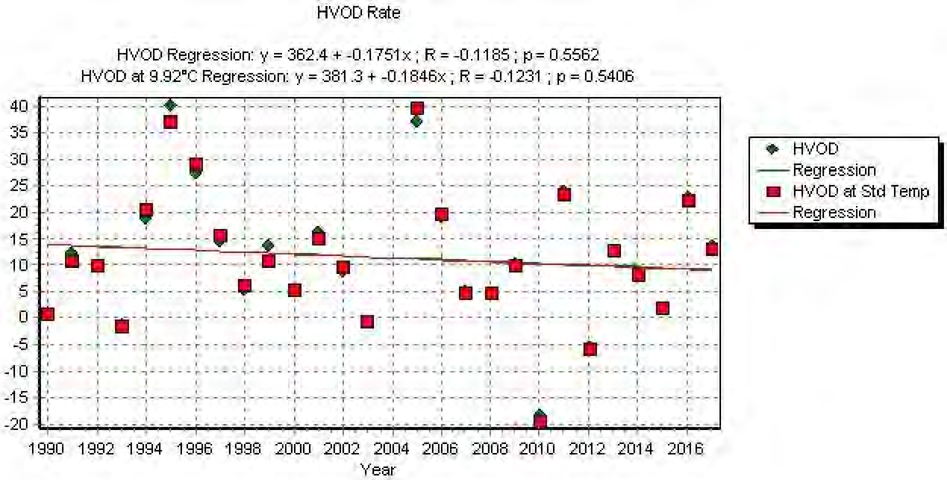
HVOD Analysis

Lake: LAKE ROTORANGI

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

Date From: 01/01/1990 **Date To:** 31/12/2017

Analysis Period	Average	Observed DO	Observed Rate Corrected to 9.9 °C (mg/m3/day)



LAKE ROTORANGI

L2 & L3 1990-2018 (1 Jan 1990 - 31 Dec 2017)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	0.06	(-0.01)	0.72	(0.74)	(-0.18)			
Average Over Period	3.18	(2.81)	28.53	(611.60)	(11.40)			
Percent Annual Change (%/Year)	**1.89**	**0.00**	**2.52**	**0.00**	**0.00**	**0.88**	**0.55**	**0.18**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Jan 1990 - Dec 1990	3.93	1.50	16.33	960.00	3.73	5.06	3.76	5.37	4.48	0.43			
Jan 1991 - Dec 1991	2.79	2.61	15.88	661.25	3.35	4.40	3.72	4.88	4.09	0.34			
Jan 1992 - Dec 1992	2.96	2.33	14.00	300.00	3.42	4.54	3.56	3.85	3.84	0.25			
Jan 1993 - Dec 1993	2.20	4.47	15.80	140.00	3.09	3.74	3.72	2.85	3.35	0.22			
Jan 1994 - Dec 1994	1.70	2.58	28.75	595.00	2.81	4.41	4.48	4.74	4.11	0.44			
Jan 1995 - Dec 1995	2.73	2.82	30.50	388.33	3.33	4.30	4.55	4.18	4.09	0.27			
Jan 1996 - Dec 1996	2.70	3.04	22.25	567.50	3.32	4.22	4.15	4.68	4.09	0.28			
Jan 1997 - Dec 1997	1.69	2.98	16.00	561.25	2.80	4.24	3.73	4.66	3.86	0.40			
Jan 1998 - Dec 1998	2.41	2.47	50.25	677.50	3.19	4.47	5.19	4.91	4.44	0.44			
Jan 1999 - Dec 1999	2.58	3.77	22.78	601.11	3.26	3.95	4.18	4.75	4.04	0.31			
Jan 2000 - Dec 2000	3.04	2.71	23.50	778.75	3.45	4.35	4.22	5.09	4.28	0.34			
Jan 2001 - Dec 2001	2.40	4.02	12.75	762.50	3.19	3.87	3.45	5.07	3.89	0.42			
Jan 2002 - Dec 2002	3.93	2.19	28.00	836.25	3.73	4.61	4.44	5.19	4.49	0.30			
Jan 2003 - Dec 2003	1.54	3.23	29.63	615.00	2.69	4.14	4.52	4.78	4.03	0.47			
Jan 2004 - Dec 2004	4.20	0.92	51.63	885.00	3.80	5.63	5.22	5.26	4.98	0.40			
Jan 2005 - Dec 2005	2.75	2.97	21.13	557.50	3.34	4.24	4.09	4.66	4.08	0.28			
Jan 2006 - Dec 2006	1.50	3.09	15.75	490.00	2.67	4.19	3.71	4.49	3.77	0.40			
Jan 2007 - Dec 2007	5.01	2.58	25.30	675.00	4.00	4.42	4.32	4.91	4.41	0.19			
Jan 2008 - Dec 2008	2.29	3.43	18.00	645.83	3.13	4.07	3.88	4.85	3.98	0.35			
Jan 2009 - Dec 2009	3.94	3.03	18.08	632.50	3.73	4.22	3.89	4.82	4.16	0.24			
Jan 2010 - Dec 2010	4.47	2.50	22.67	678.33	3.87	4.45	4.18	4.91	4.35	0.22			
Jan 2011 - Dec 2011	3.34	2.39	37.67	738.33	3.55	4.51	4.82	5.02	4.48	0.33			
Jan 2012 - Dec 2012	3.33	2.60	33.00	605.00	3.55	4.41	4.65	4.76	4.34	0.28			
Jan 2013 - Dec 2013	5.68	2.89	27.25	287.50	4.14	4.28	4.41	3.79	4.15	0.13			
Jan 2014 - Dec 2014	5.08	3.37	28.29	592.86	4.01	4.09	4.46	4.74	4.32	0.17			
Jan 2015 - Dec 2015	4.88	2.29	120.00	684.29	3.97	4.56	6.29	4.92	4.93	0.49			
Jan 2016 - Dec 2016	3.64	2.86	23.43	478.57	3.65	4.29	4.22	4.46	4.15	0.18			
Jan 2017 - Dec 2017	3.97	2.57	32.00	376.00	3.74	4.42	4.61	4.14	4.23	0.19			

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
Averages	**3.24**	**2.79**	**28.59**	**598.97**	**3.45**	**4.36**	**4.30**	**4.67**	**4.19**	**0.06**	**0.01**	**0.01**	**0.0530**

SUMMARY:

PAC = 0.88 ± 0.55 % per year
P-Value = 0.18

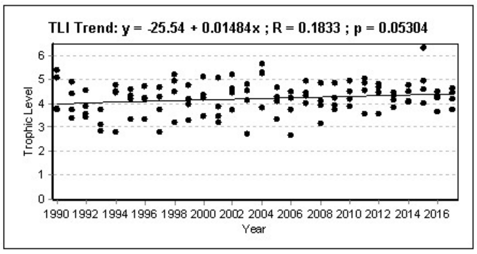
TLI Value = 4.19 ± 0.06 TLI units
TLI Trend = 0.01 ± 0.01 TLI units per year
P-Value = 0.0530

ASSESSMENT:

Eutrophic
Probable Degredation

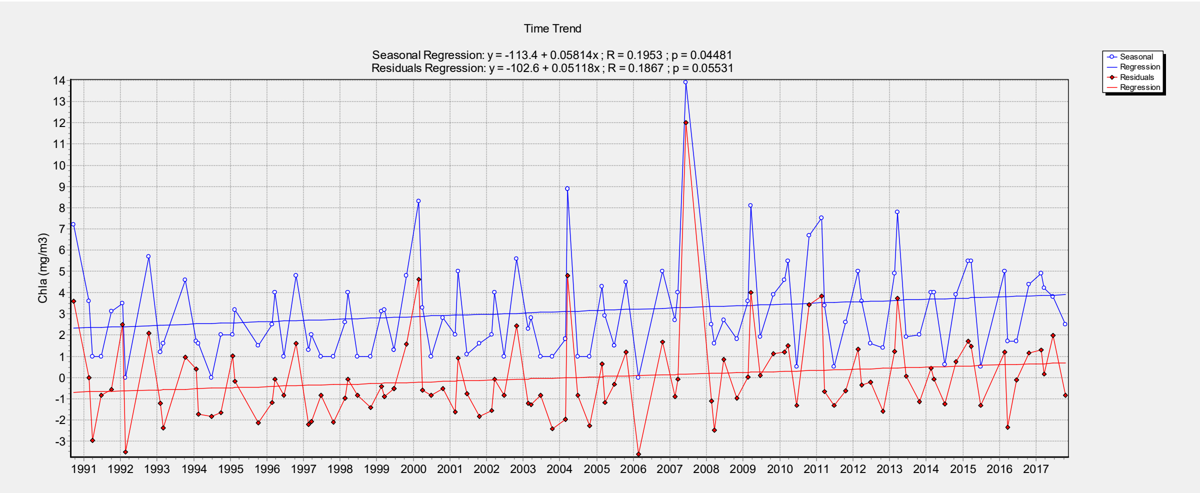
The guide used in the PAC average P-Value evaluation is

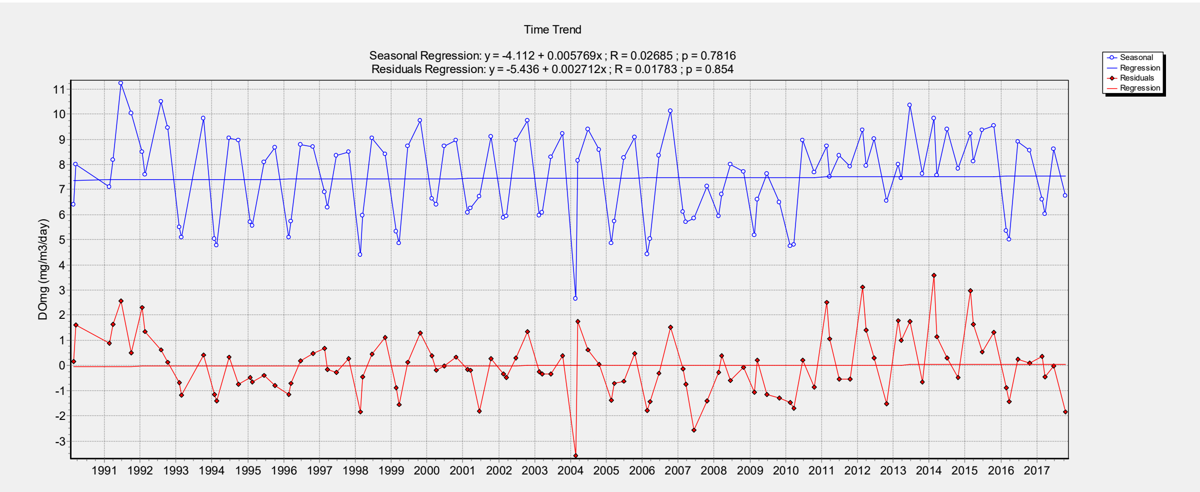
P-Value Range	Interpretation
P ≤ 0.1	Definite Change
0.1 < P ≤ 0.2	Probable Change
0.2 < P ≤ 0.3	Possible Change
0.3 < P	No Change

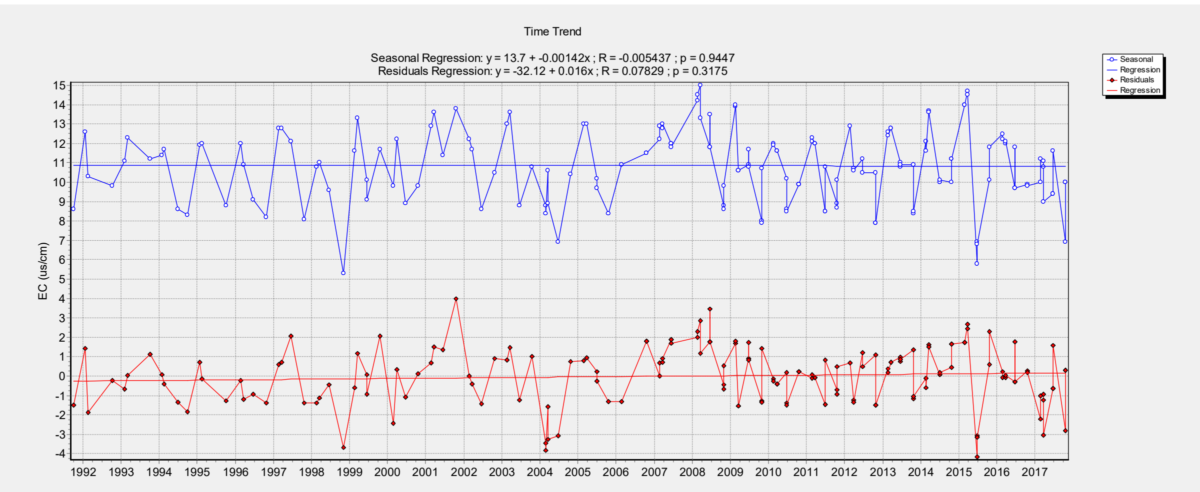


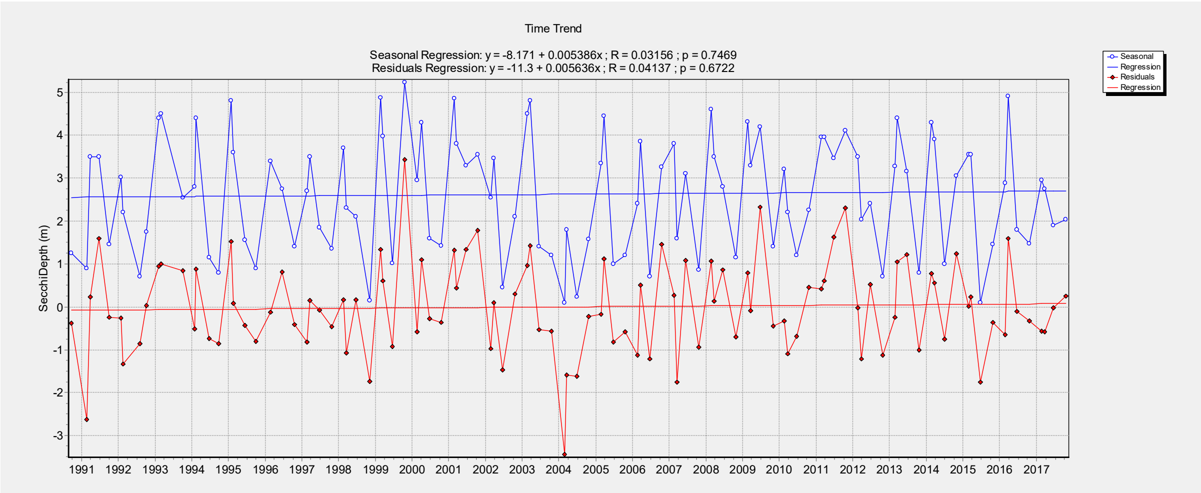
Appendix 3

L2 trends – Physical parameters

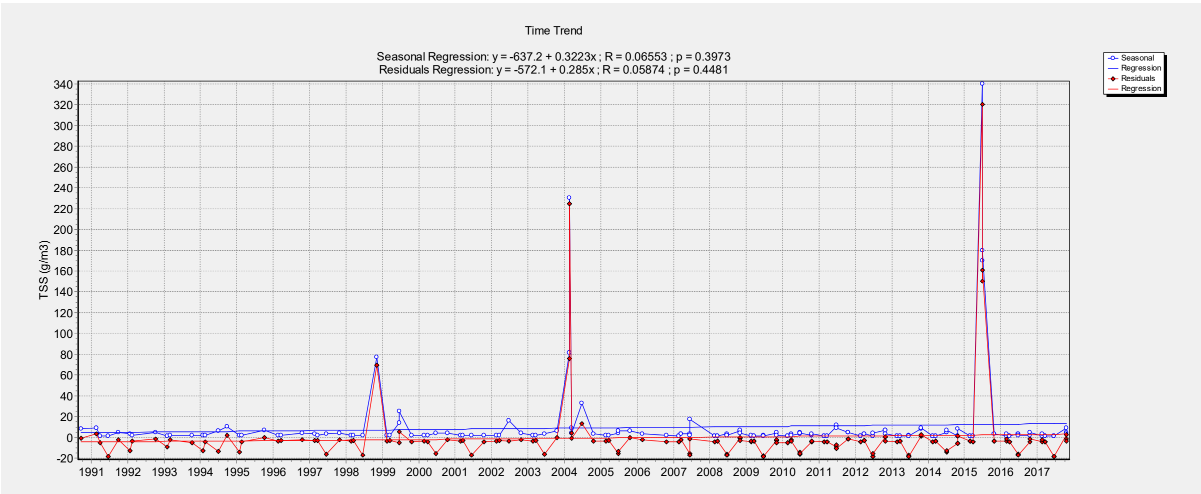




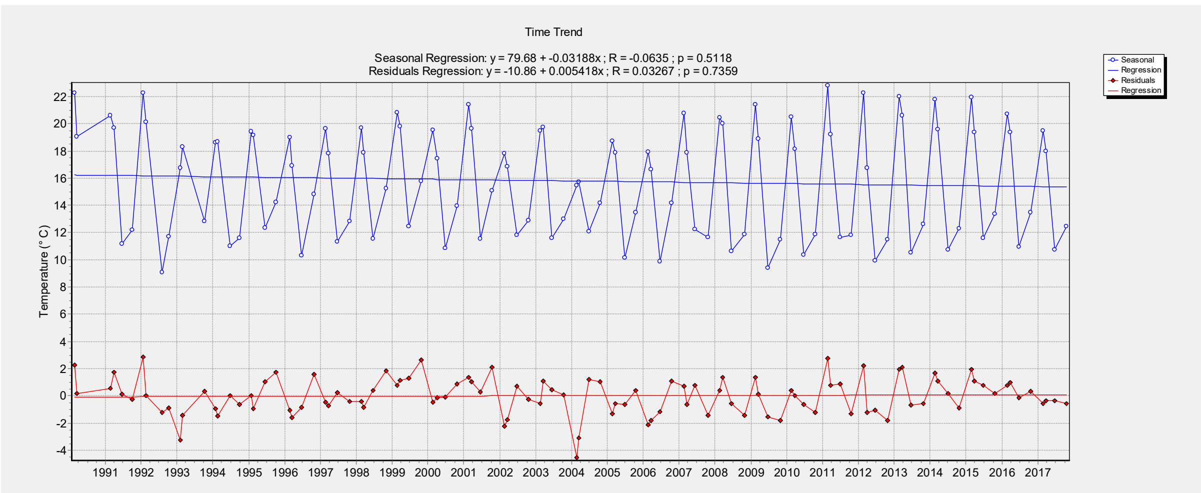




Time Trend
Seasonal Regression: y = -8.171 + 0.005386x ; R = 0.03156 ; p = 0.7469
Residuals Regression: y = -11.3 + 0.005636x ; R = 0.04137 ; p = 0.6722
Seasonal
Regression
Residuals
Regression
SecchiDepth (m)

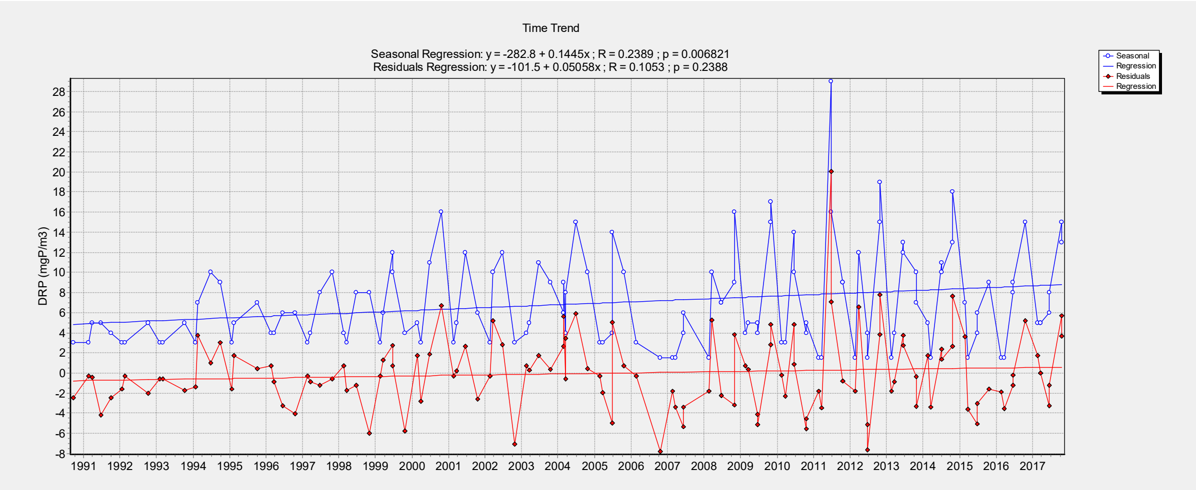


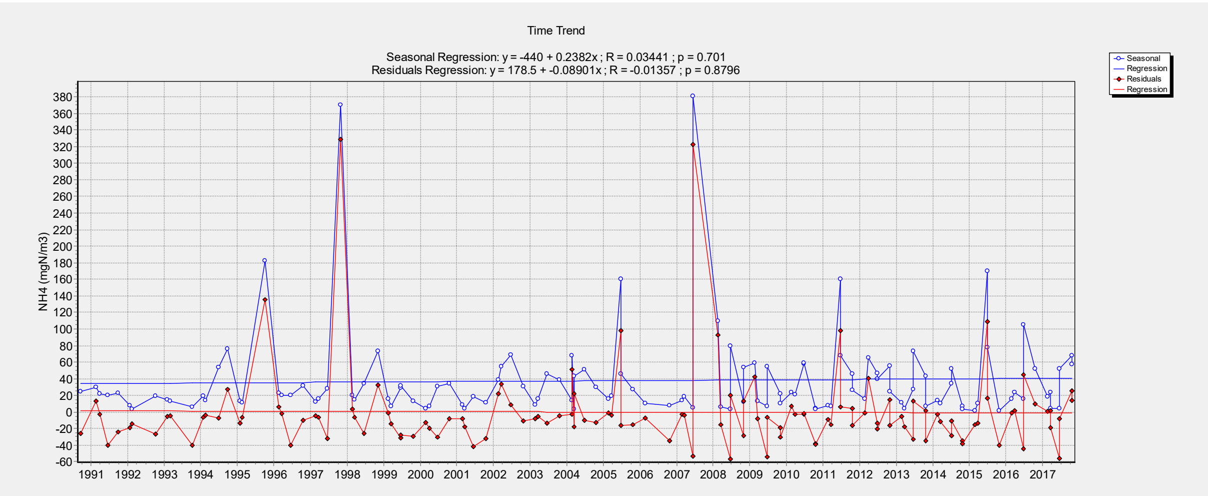
Time Trend
Seasonal Regression: y = -637.2 + 0.3223x ; R = 0.06553 ; p = 0.3973
Residuals Regression: y = -572.1 + 0.285x ; R = 0.05874 ; p = 0.4481
Seasonal
Regression
Residuals
Regression
TSS (g/m3)

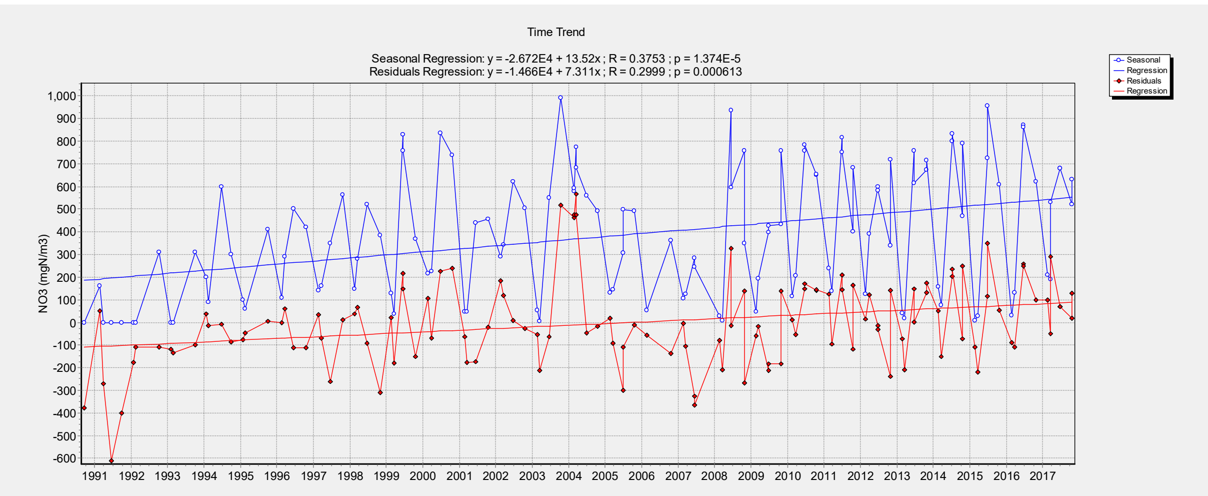


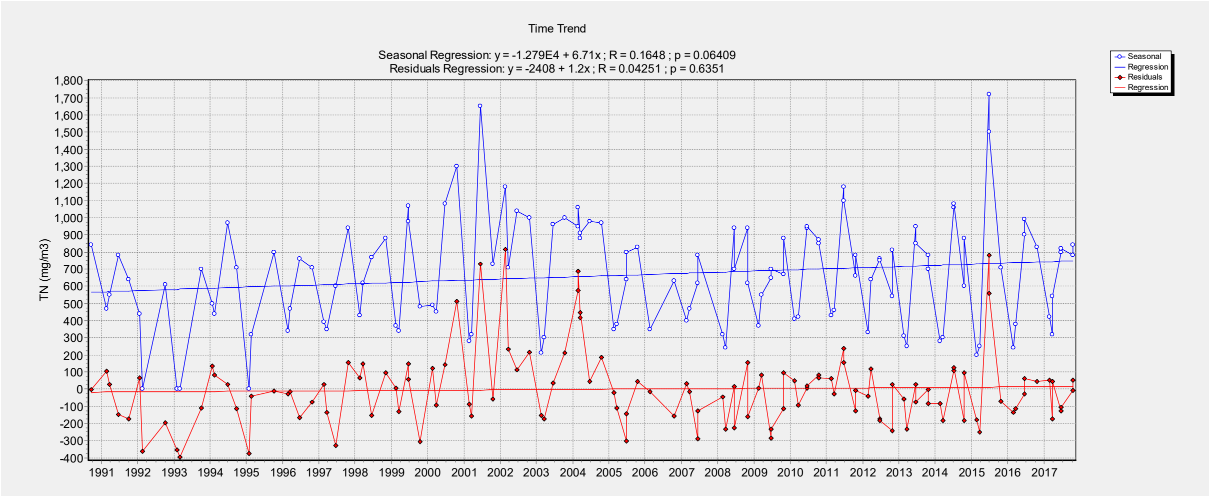
Time Trend
Seasonal Regression: y = 79.68 + -0.03188x ; R = -0.0635 ; p = 0.5118
Residuals Regression: y = -10.86 + 0.005418x ; R = 0.03267 ; p = 0.7359
Seasonal
Regression
Residuals
Regression
Temperature (° C)

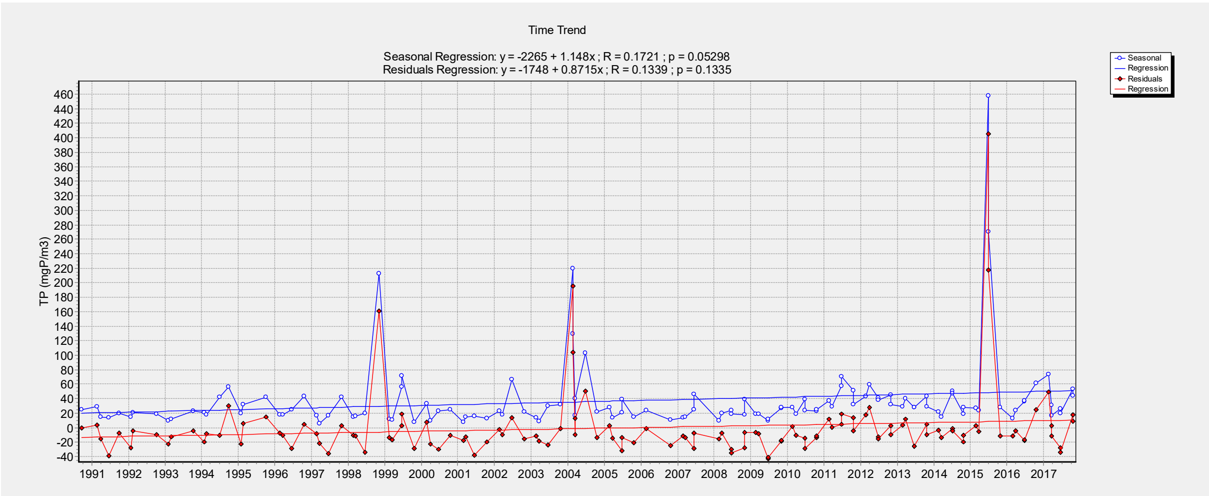
L2 – Nutrients








Time Trend
Seasonal Regression: y = -1.279E4 + 6.71x ; R = 0.1648 ; p = 0.06409
Residuals Regression: y = -2408 + 1.2x ; R = 0.04251 ; p = 0.6351
TN (mg/m3)
Seasonal
Regression
Residuals
Regression
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017


Time Trend
Seasonal Regression: y = -2265 + 1.148x ; R = 0.1721 ; p = 0.05298
Residuals Regression: y = -1748 + 0.8715x ; R = 0.1339 ; p = 0.1335
TP (mgP/m3)
Seasonal
Regression
Residuals
Regression
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017

HVOD Analysis

Lake: LAKE ROTORANGI

Stations: L2 (Tangahoe Valley Rd)

Date From: 01/01/1990 **Date To:** 31/12/2017

Analysis Period	Average	Observed DO	Observed Rate Corrected to 10.0 °C (mg/m3/day)
01-Jan-1990 - 31-Mar-1990	11.7	-43.3	-38.4
01-Jan-1991 - 31-Mar-1991	11.58	5.1	4.6
01-Jan-1992 - 30-Mar-1992	9.94	5.6	5.6
01-Jan-1993 - 31-Mar-1993	9.4	-11.2	-11.7
01-Jan-1994 - 31-Mar-1994	8.72	-35.2	-38.5
01-Jan-1995 - 31-Mar-1995	11.58	30.7	27.5
01-Jan-1996 - 30-Mar-1996	9.29	8.9	9.4
01-Jan-1997 - 31-Mar-1997	8.82	-24.8	-26.9
01-Jan-1998 - 31-Mar-1998	8.53	-0.6	-0.7
01-Jan-1999 - 31-Mar-1999	13.14	-7.9	-6.3
01-Jan-2000 - 30-Mar-2000	0.0	0.0	0.0
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	-38.4
01-Jan-2005 - 05-Apr-2005	9.03	19.0	20.4
01-Jan-2006 - 31-Mar-2006	9.51	19.4	20.1
01-Jan-2007 - 31-Mar-2007	10.04	5.8	5.8
01-Jan-2008 - 30-Mar-2008	9.73	-6.5	-6.6
01-Jan-2009 - 31-Mar-2009	10.36	-9.4	-9.2
01-Jan-2010 - 31-Mar-2010	8.96	-20.4	-22.0
01-Jan-2011 - 31-Mar-2011	10.63	9.5	9.1
01-Jan-2012 - 30-Mar-2012	9.73	-14.8	-15.1
01-Jan-2013 - 31-Mar-2013	10.07	6.4	6.4
01-Jan-2014 - 31-Mar-2014	11.0	15.0	14.0
01-Jan-2015 - 31-Mar-2015	9.74	1.6	1.6
01-Jan-2016 - 30-Mar-2016	10.57	23.5	22.6
01-Jan-2017 - 31-Mar-2017	10.71	13.8	13.1
Average	**9.73**	**-1.8**	**-2.0**

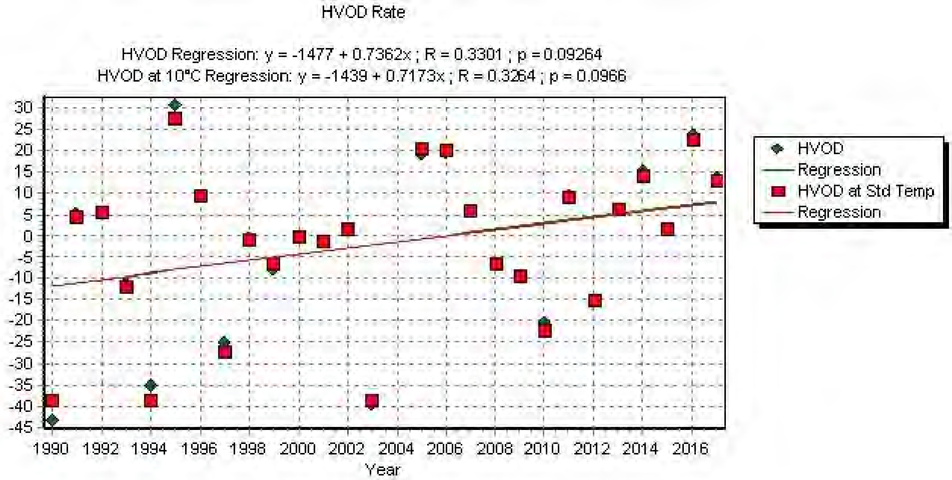
HVOD Analysis

Lake: LAKE ROTORANGI

Stations: L2 (Tangahoe Valley Rd)

Date From: 01/01/1990 **Date To:** 31/12/2017

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



LAKE ROTORANGI

L2 1990-2018 (1 Jan 1990 - 31 Dec 2017)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	0.06	(0.01)	(1.25)	(2.77)	(0.71)			
Average Over Period	3.13	(2.63)	(35.53)	(636.64)	(-1.78)			
Percent Annual Change (%/Year)	**1.92**	**0.00**	**0.00**	**0.00**	**0.00**	**0.38**	**0.38**	**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			
Jan 2015 - Dec 2015	3.83	2.16	194.75	917.50	3.70	4.63	6.90	5.31	5.14	0.67			
Jan 2016 - Dec 2016	3.35	2.77	15.00	502.50	3.55	4.33	3.65	4.52	4.01	0.24			
Jan 2017 - Dec 2017	4.55	2.41	40.67	426.67	3.89	4.50	4.92	4.31	4.40	0.21			

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
Averages	**3.30**	**2.60**	**34.80**	**618.17**	**3.45**	**4.45**	**4.46**	**4.71**	**4.27**	**0.07**	**0.01**	**0.01**	**0.2585**

SUMMARY:

PAC = 0.38 ± 0.38 % per year
P-Value = 0.37

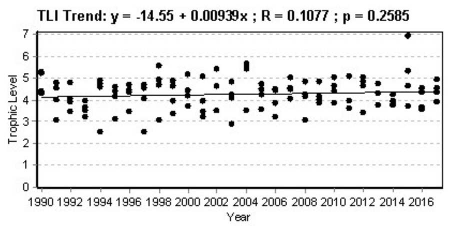
TLI Value = 4.27 ± 0.07 TLI units
TLI Trend = 0.01 ± 0.01 TLI units per year
P-Value = 0.2585

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



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
Averages	3.33	2.98	20.34	541.01	3.41	4.30	3.96		3.89	0.07	0.02	0.01	0.0438

SUMMARY:

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

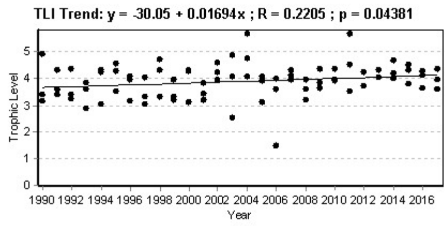
TLI Value = 3.89 ± 0.07 TLI units
TLI Trend = 0.02 ± 0.01 TLI units per year
P-Value = 0.0438

ASSESSMENT:

Mesotrophic
No Change

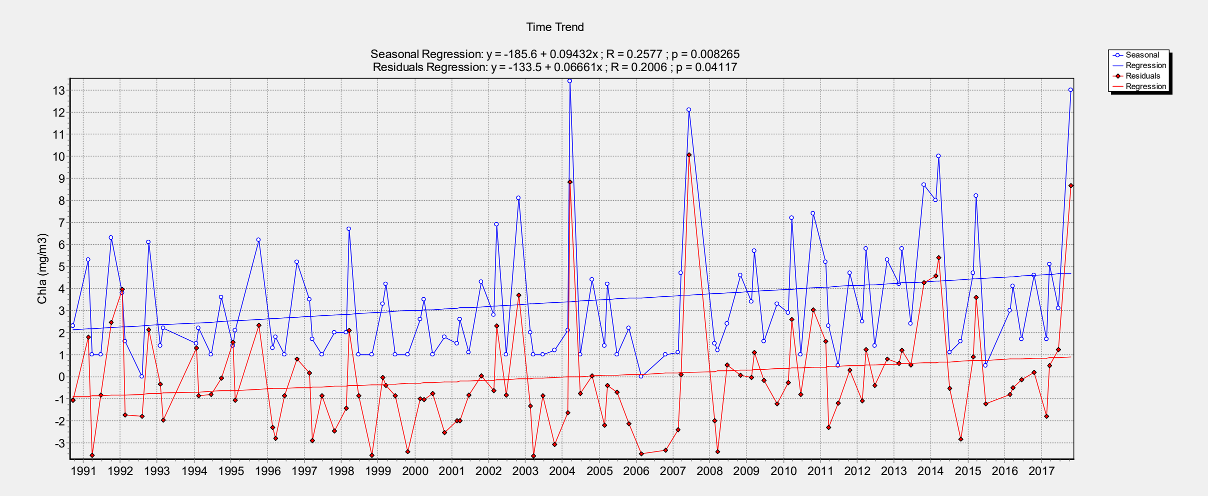
The guide used in the PAC average P-Value evaluation is

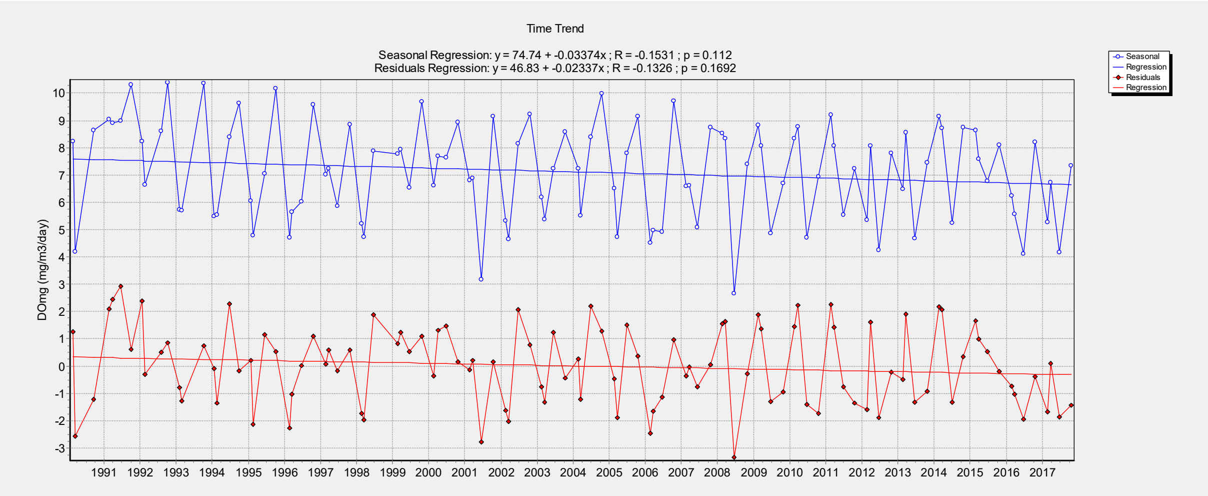
P-Value Range	Interpretation
P ≤ 0.1	Definite Change
0.1 < P ≤ 0.2	Probable Change
0.2 < P ≤ 0.3	Possible Change
0.3 < P	No Change

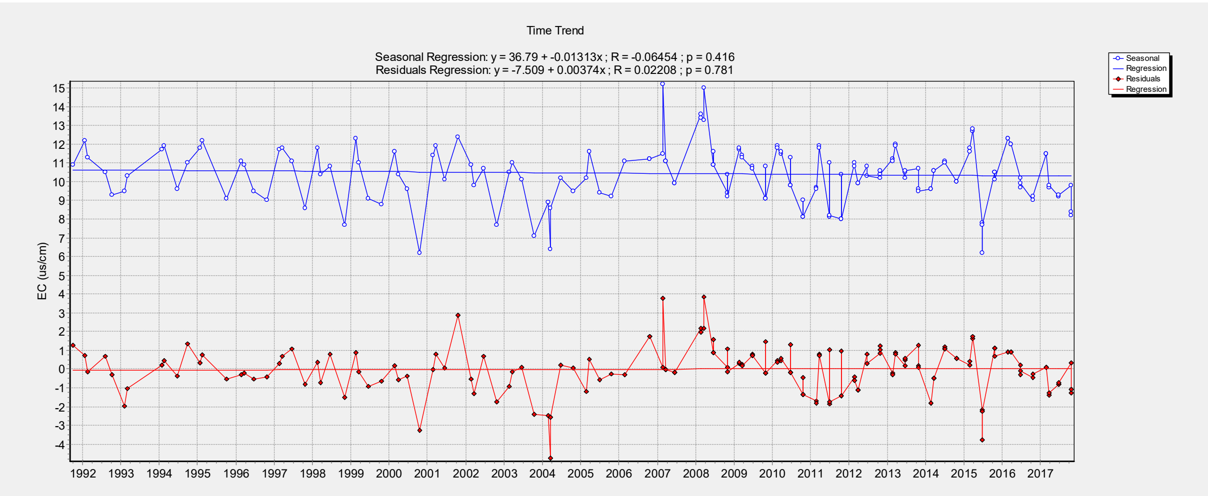


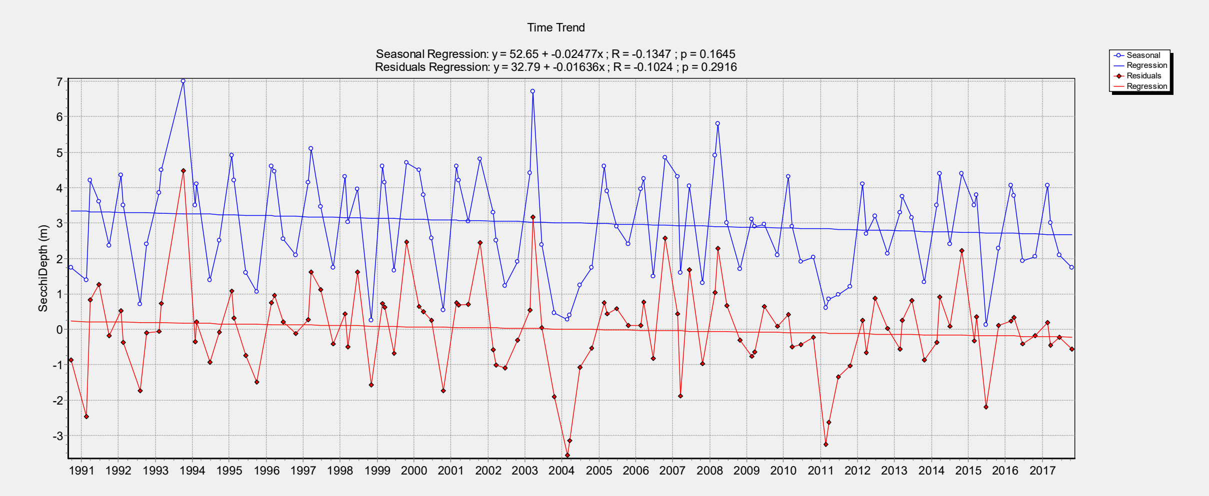
Appendix 4

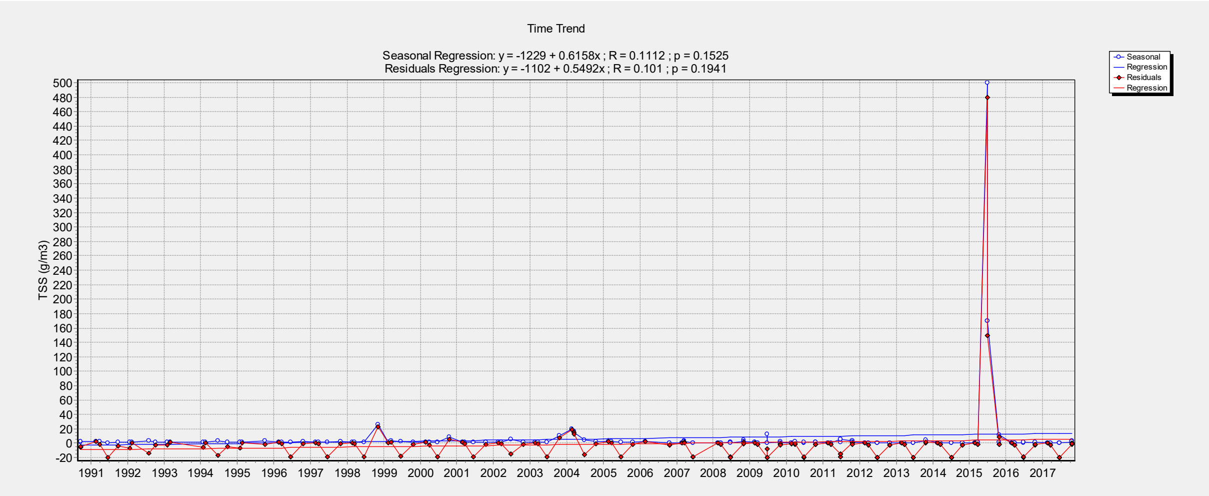
L3 – Physical parameters

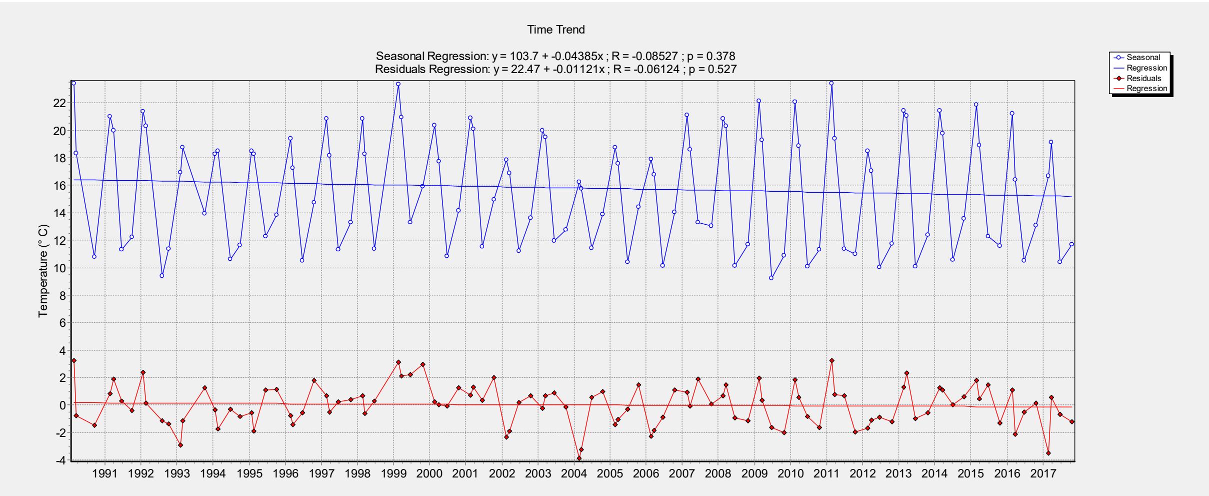




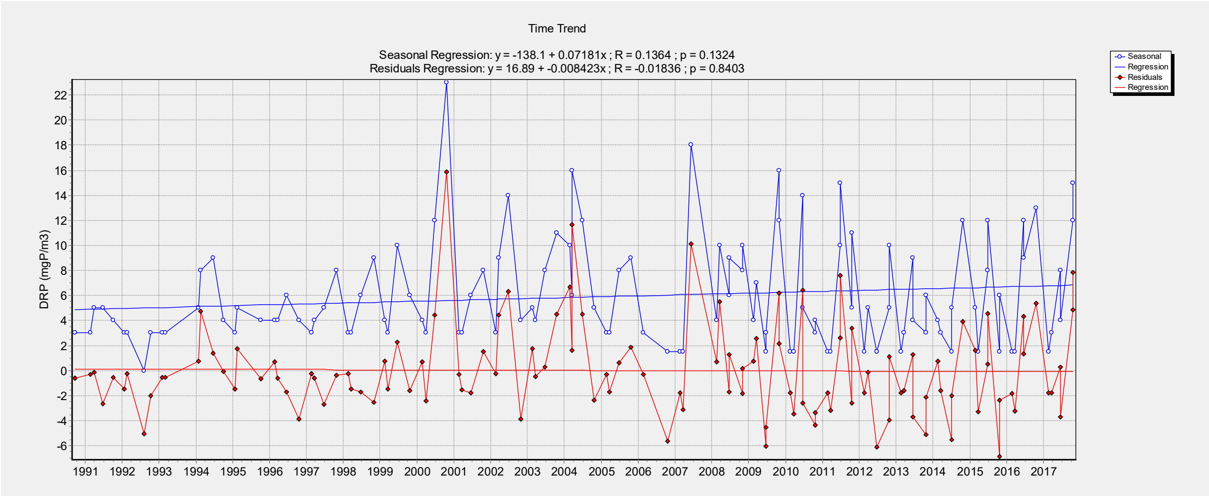


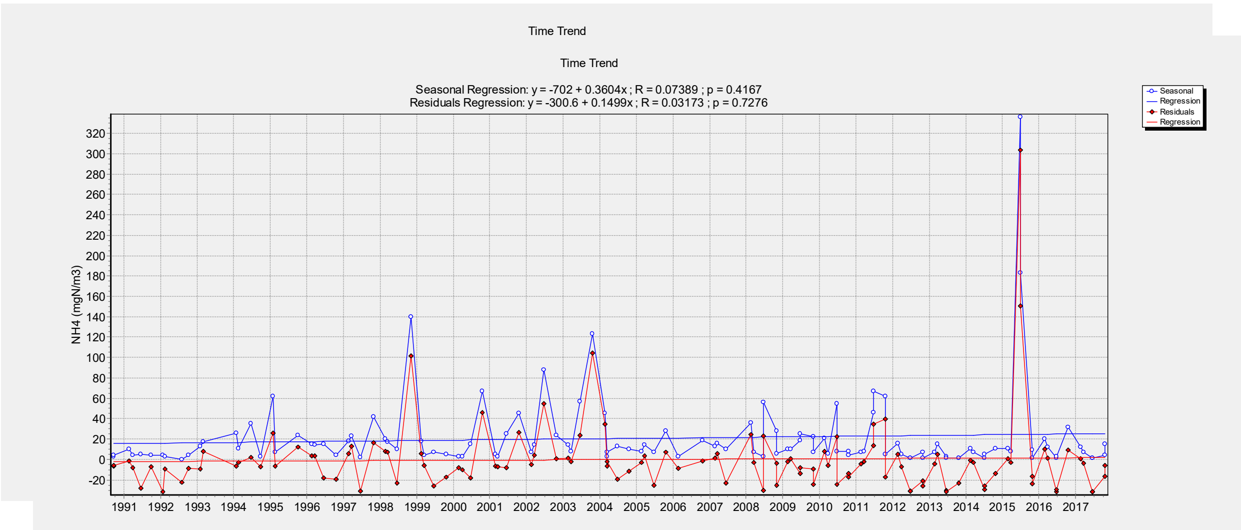

Time Trend
Seasonal Regression: y = 52.65 + -0.02477x ; R = -0.1347 ; p = 0.1645
Residuals Regression: y = 32.79 + -0.01636x ; R = -0.1024 ; p = 0.2916
SecchiDepth (m)
Seasonal
Regression
Residuals
Regression

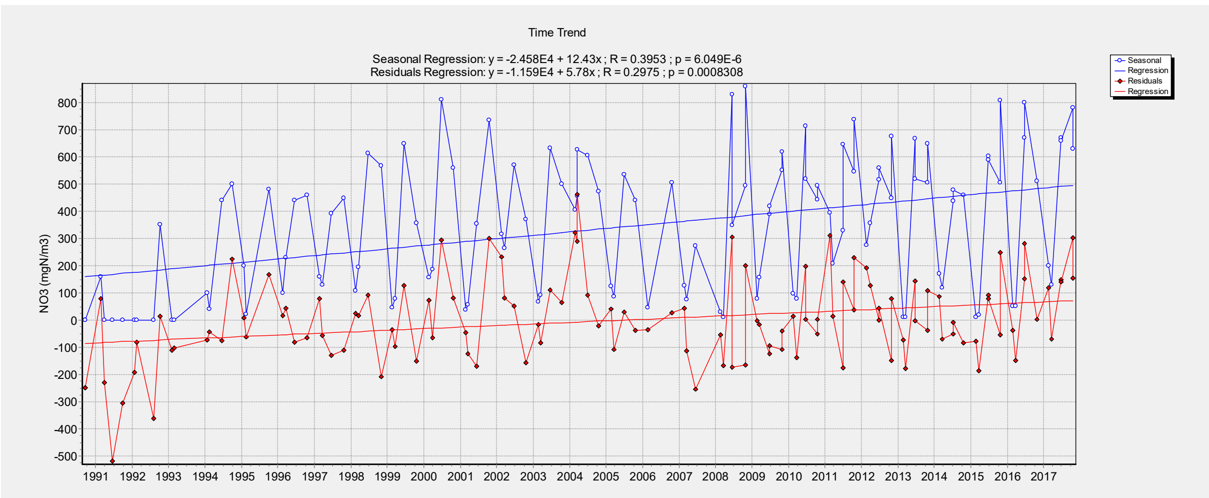

Time Trend
Seasonal Regression: y = -1229 + 0.6158x ; R = 0.1112 ; p = 0.1525
Residuals Regression: y = -1102 + 0.5492x ; R = 0.101 ; p = 0.1941
TSS (g/m3)
Seasonal
Regression
Residuals
Regression

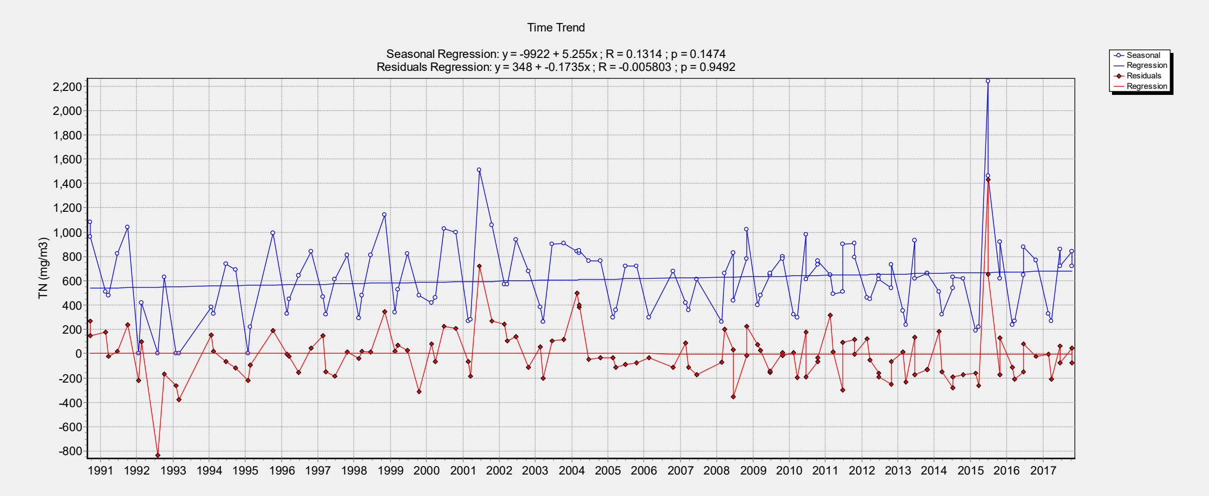

Time Trend
Seasonal Regression: y = 103.7 + -0.04385x ; R = -0.08527 ; p = 0.378
Residuals Regression: y = 22.47 + -0.01121x ; R = -0.06124 ; p = 0.527
Temperature (° C)
Seasonal
Regression
Residuals
Regression

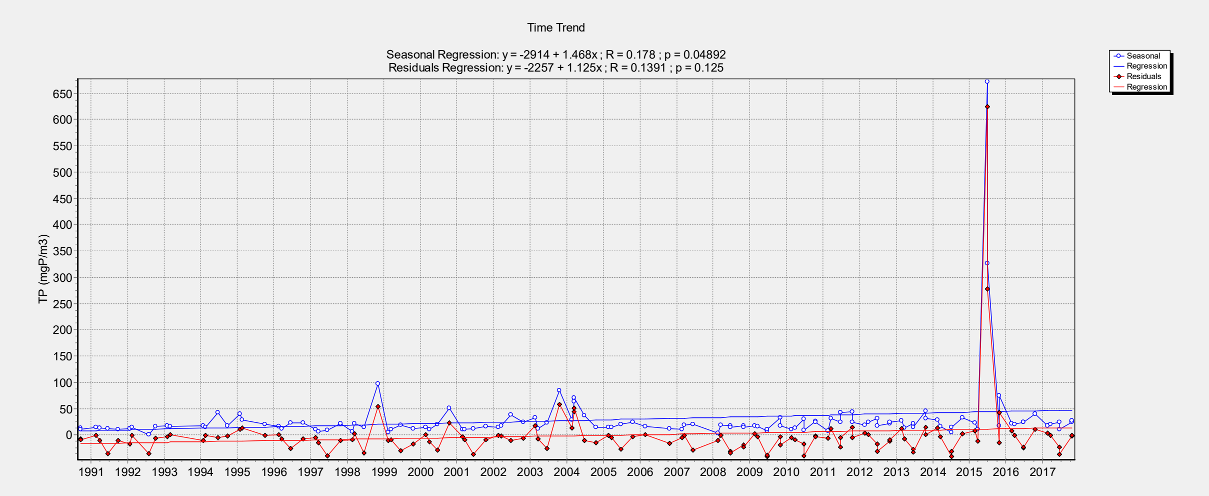
L3 – Nutrients








Time Trend
Seasonal Regression: y = -9922 + 5.255x ; R = 0.1314 ; p = 0.1474
Residuals Regression: y = 348 + -0.1735x ; R = -0.005803 ; p = 0.9492
TN (mg/m3)
Seasonal
Regression
Residuals
Regression


Time Trend
Seasonal Regression: y = -2914 + 1.468x ; R = 0.178 ; p = 0.04892
Residuals Regression: y = -2257 + 1.125x ; R = 0.1391 ; p = 0.125
TP (mgP/m3)
Seasonal
Regression
Residuals
Regression

HVOD Analysis

Lake: LAKE ROTORANGI

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

Date From: 01/01/1990 **Date To:** 31/12/2017

Analysis Period	Average	Observed DO	Observed Rate Corrected to 9.8 °C (mg/m3/day)
01-Jan-1990 - 31-Mar-1990	9.31	45.4	46.8
01-Jan-1991 - 31-Mar-1991	11.6	19.4	17.1
01-Jan-1992 - 30-Mar-1992	9.76	14.6	14.6
01-Jan-1993 - 31-Mar-1993	9.4	8.8	9.0
01-Jan-1994 - 31-Mar-1994	8.62	16.1	17.5
01-Jan-1995 - 31-Mar-1995	10.62	49.8	46.9
01-Jan-1996 - 30-Mar-1996	8.59	45.7	49.5
01-Jan-1997 - 31-Mar-1997	8.51	29.1	31.7
01-Jan-1998 - 31-Mar-1998	8.09	11.8	13.3
01-Jan-1999 - 31-Mar-1999	13.49	35.3	27.3
01-Jan-2000 - 04-Apr-2000	10.0	5.8	5.7
01-Jan-2001 - 31-Mar-2001	11.39	34.0	30.4
01-Jan-2002 - 31-Mar-2002	8.6	16.5	17.9
01-Jan-2003 - 31-Mar-2003	9.47	-0.8	-0.8
01-Jan-2005 - 31-Mar-2005	8.86	55.0	58.5
01-Jan-2006 - 31-Mar-2006	9.34	18.8	19.4
01-Jan-2007 - 31-Mar-2007	10.33	4.5	4.3
01-Jan-2008 - 30-Mar-2008	9.25	16.0	16.6
01-Jan-2009 - 31-Mar-2009	9.76	29.9	29.9
01-Jan-2010 - 31-Mar-2010	8.98	-15.6	-16.4
01-Jan-2011 - 31-Mar-2011	9.88	38.4	38.1
01-Jan-2012 - 30-Mar-2012	8.78	4.0	4.3
01-Jan-2013 - 31-Mar-2013	9.78	19.7	19.7
01-Jan-2014 - 31-Mar-2014	10.92	2.8	2.6
01-Jan-2015 - 31-Mar-2015	9.51	2.8	2.8
01-Jan-2016 - 30-Mar-2016	10.08	22.2	21.7
01-Jan-2017 - 31-Mar-2017	10.61	14.0	13.2
Average	**9.76**	**20.2**	**20.1**

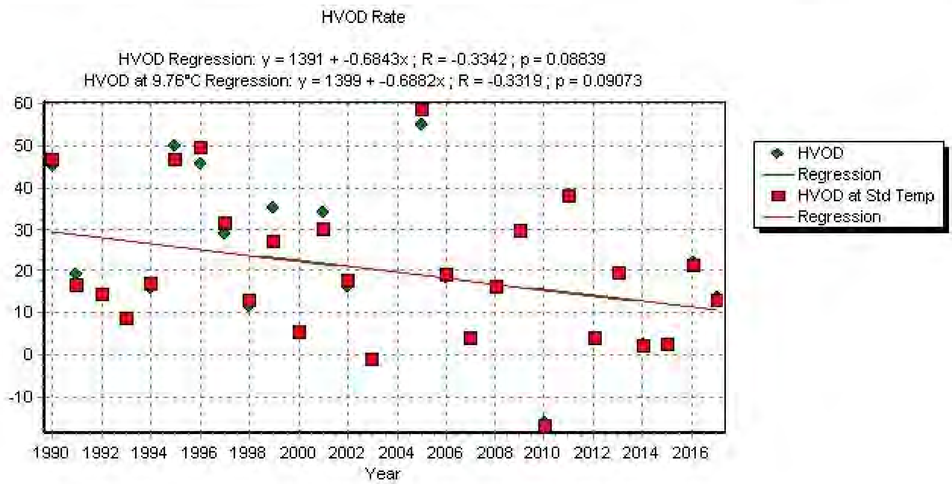
HVOD Analysis

Lake: LAKE ROTORANGI

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

Date From: 01/01/1990 **Date To:** 31/12/2017

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



LAKE ROTORANGI

L3 1990-2018 (1 Jan 1990 - 31 Dec 2017)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	(0.06)	(-0.02)	(0.06)	(-2.32)	(-0.69)			
Average Over Period	(3.24)	(3.00)	(20.52)	(573.37)	(20.06)			
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			
Jan 2015 - Dec 2015	6.45	2.42	16.50	205.00	4.28	4.49	3.77		4.18	0.21			
Jan 2016 - Dec 2016	3.55	2.95	21.00	255.00	3.62	4.25	4.08		3.98	0.19			
Jan 2017 - Dec 2017	3.40	2.73	19.00	300.00	3.57	4.35	3.95		3.96	0.22			

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
Averages	**3.33**	**2.98**	**20.34**	**541.01**	**3.41**	**4.30**	**3.96**		**3.89**	**0.07**	**0.02**	**0.01**	**0.0438**

SUMMARY:

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

TLI Value = 3.89 ± 0.07 TLI units
TLI Trend = 0.02 ± 0.01 TLI units per year
P-Value = 0.0438

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