Lake Rotorangi

State of the Environment Monitoring
Annual Report
2021-2024
Technical Report 2024-98

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Taranaki Regional Council

Lake Rotorangi

State of the Environment Monitoring Annual Report 2021-2024

Technical Report 2024-98

Taranaki Regional Council
Private Bag 713
Stratford

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Executive summary

Lake Rotorangi was formed in May 1984 by the construction of an earth fill dam on the Pātea River for hydroelectric power generation. In recognition of both the regionally significant recreational resource created, and the considerable environmental impacts which might occur, a comprehensive monitoring programme was developed and implemented for the lake. This report presents the most recent monitoring results, covering the period from 1 July 2021 to 30 June 2024.

Each year, four water quality surveys are undertaken at two sites. One site is located in the mid reaches of the lake (site LRT000300), while the second site is located closer to the dam (site LRT000450).

Thermal stratification patterns observed in 2021-2024 were comparable to previous monitoring periods. Oxygen depletion was frequently observed in the lower water column.

Water quality results were variable across the monitoring period. In 2021/22, annual median concentrations were elevated for a range of parameters, including total nitrogen, nitrite/nitrate and chlorophyll *a*. These results produced an elevated trophic level index (TLI) score corresponding to the upper eutrophic range (indicative of degraded lake water quality). Concentrations of key water quality parameters were more typical of previous results in 2022/23 and were much lower than typical results in 2023/24. In 2023/24, these results produced a lower TLI score corresponding to the middle of the mesotrophic range (indicative of fair water quality). Historically, the TLI for Lake Rotorangi has tended to sit very close to the mesotrophic-eutrophic threshold.

Based on the attributes set out in the National Policy Statement for Freshwater Management (2020), ammonia and *E. coli* concentrations classify the lake in the 'A' band, or minimally impacted compared to reference conditions. Total nitrogen concentrations classify the lake as being in the 'C' band, or moderately impacted compared to reference conditions. Total phosphorus classifies the upper lake as moderately impacted and the lower lake as mildly impacted. Typical (median) chlorophyll *a* concentrations correspond to the 'A' band, whereas maximum concentrations correspond to the C and B bands in the upper and lower monitoring sites, respectively. Lake bottom and mid-hypolimnetic dissolved oxygen concentrations at both sites were in the D band category which is below the national bottom line, indicative of significant stress on fish species and the potential for nutrient release from lakebed sediments.

Long-term trend analyses (comprising the entire monitoring record) found evidence of improving trends for nine out of 26 site-parameter combinations that were assessed. Evidence of long-term degrading trends was discovered for 12 site-parameter combinations, and the remaining five combinations lacked sufficient evidence to establish a trend direction. The trends with the highest certainty were the improving trends for dissolved reactive phosphorous and ammoniacal nitrogen, the degrading trends for total phosphorous and chlorophyll *a*, and degrading trends in TLI. The rate of annual change varied by parameter. TLI was found to be increasing relatively slowly, corresponding to an average increase in TLI of 0.2% per year.

Short-term trend analysis (from 2014 to 2024) found evidence of improving trends for 16 out of 24 site-parameter combinations. For the remaining eight site-parameter combinations, there was insufficient evidence to establish trend direction. No degrading trends were observed. The trends with the highest certainty were the improving trends for total phosphorous, dissolved reactive phosphorous, ammoniacal nitrogen and chlorophyll *a*, The rate of annual change in these trends varied by parameter, but were generally much higher than those seen with the long-term trends.

The results from the macrophyte survey carried out in April 2024 were comparable to the previous survey carried out in 2020/21 and show a continued trend of range expansion of the highly invasive *Ceratophyllum demersum* (also known as hornwort). First detected in 2012, hornwart has since spread throughout the lake and is now the dominant species across the entire surveyed area.

The results from a spatial water quality modelling investigation recently carried out to support the development of the proposed Regional Land and Freshwater Plan are also presented here. The key sources of total nitrogen and phosphorous loads delivered to Lake Rotorangi were estimated, and a range of hypothetical management scenarios and lake water quality responses were also simulated. These assessments highlight the importance of continuing to promote riparian management, soil conservation and best practice dairy effluent management throughout the region. However, it is also clear based on the data that additional tools and strategies will be required to help achieve improved long-term water quality outcomes.

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1. Introduction

1.1 General

The *Resource Management Act 1991* (RMA) established requirements for local authorities to undertake environmental monitoring. Section 35 of the RMA requires local authorities to monitor 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, Taranaki Regional Council (the Council) has established a state of the environment monitoring (SoE) 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 1994*. The overall aim being to report on the state and trends of freshwater health to enhance the effectiveness of RMA policies and to support the region's freshwater ecosystems.

The SoE programme is made up of several individual monitoring activities, many of which are undertaken and managed on an annual basis (from 1 July to 30 June). For these monitoring activities, summary reports are produced to summarise regional environmental monitoring in relation to state and trends. SoE reports act as 'building blocks' towards the preparation of the regional state of the environment report every five years.

This report summarises the results of the Lake Rotorangi SoE programme over the 2021-2024 monitoring period.

1.2 Lake Rotorangi

Lake Rotorangi was formed in May 1984 by the construction of an earthfill dam on the Pātea River for a hydro-electric power scheme. An initial sampling programme was designed to assess the state and environmental consequences of the new lake. The results of this intensive monitoring programme were published in the 'Lake Rotorangi - Monitoring a New Hydro Lake' (Taranaki Catchment Board 1988) report. Results of monitoring since this time are published in annual reports listed in the references of this report.

This initial monitoring determined that the lake was mildly eutrophic or mesotrophic. Further, the annual thermal stratification cycle which the lake undergoes was identified as the single most important factor influencing water quality within the lake.

Since monitoring began, the trophic state of Lake Rotorangi has been increasing (degrading) at a very slow rate, in the order of 0.02±0.01 units per year. Initial monitoring showed the lake was in a mesotrophic state, and has over time moved to a mildly eutrophic state. Previous analysis has determined that the trophic level is heavily influenced by high turbidity values and therefore not a true indication of actual trophic status (as determined by primary production) of the lake (Burns 2006).

The Pātea catchment upstream of the dam covers an area of 86,944ha. This includes both the Pātea River sub-catchment and the Mangaehu River sub-catchment. Approximately 841ha (1%) of this area is urban, while another 6,589ha (8%) is conservation land. The remainder of the catchment (71,514ha, 91%) is in pastoral land, with a mixture of dry stock and dairy farming in the catchment. Identifying and implementing actions to address hill country erosion is a significant focus for this catchment. Farm plans addressing land management and sediment issues cover around 43,055ha (50%) of the catchment, primarily in the area where dry stock faming is the dominant land use.

1.2.1 Lake stratification processes

Stratification is a seasonal process, which occurs when the upper water column near the surface warms much faster than the lower water column. Changes in the density of water at differing temperatures creates a physical barrier separating the upper water column (epilimnion) and lower water column (hypolimnion). Biological and chemical processes differ between the epilimnion and hypolimnion, which can cause differences in water quality between the layers.

Substantial differences in water quality can occur between the epilimnion and hypolimnion as a result of stratification. Typically, the epilimnion has the majority of primary production because light levels are highest in the upper water column. Organic detritus sinks from the epilimnion though the water column, resulting in the transfer of nutrients to the hypolimnion. Therefore over time, the concentrations of bioavailable nutrients decrease in the epilimnion compared to the hypolimnion.

Oxygen depletion may occur in the hypolimnion, because oxygen consumed by biological and chemical processes cannot be replaced due to the physical separation from the more oxygenated surface waters. Replacement of oxygen in the hypolimnion results from mixing caused by either the natural overturn processes or as a results of flood events in the river inflow. Oxygen depletion in the hypolimnion can in turn alter the pH of the hypolimnion. The increased pH in anoxic waters creates a risk of nutrient release from the lakebed sediment into the water column.

2. Monitoring methodology

2.1 Program design

The current Lake Rotorangi Monitoring programme consists of two primary components; physicochemical and biological monitoring. Sampling is undertaken at two sites along the lake, on four occasions each year. The sampling occasions are timed to target particular stratification conditions of the lake. Details of the sites are provided in Table 1 and Figure 1.

Table 1 Monitoring site locations in Lake Rotorangi

Site code	Site	Location
LRT000300	L2 (near Tāngāhoe Valley Road)	E1729856 N5626435
LRT000450	L3 (near Pātea Dam)	E1734948 N5621974

The targeted conditions are described in Table 2. Sampling in the specified months is aimed to be undertaken within seven days of the 20th of the month. The dates sampled in the 2021-2024 monitoring period are also provided in Table 2.

Table 2 Seasonal sampling dates

Season	Month	Target conditions	Sampling date (2021/22)	Sampling date (2022/23)	Sampling date (2023/24)
Spring	October	Pre-stratification	21 Oct 2021	19 Oct 2022	25 Oct 2023
Late Summer	February	Stable stratification	21 Feb 2022	20 Feb 2023	21 Feb 2024
Early Autumn	March	Pre-overturn	21 Mar 2022	22 Mar 2023	27 Mar 2024
Winter	June	Post-overturn	29 Jun 2022	22 Jun 2023	19 Jun 2024

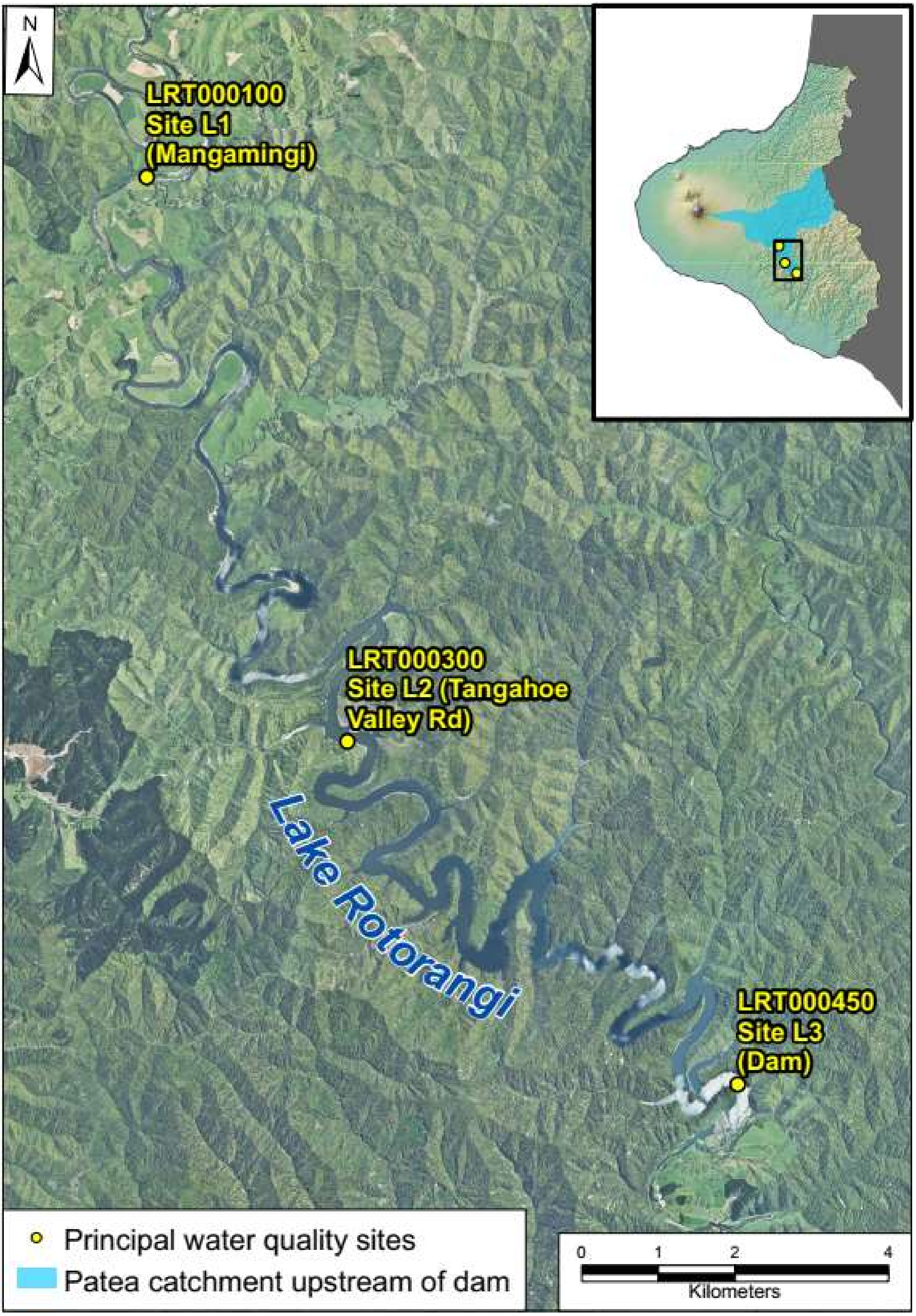

Figure 1 Location of monitoring sites in Lake Rotorangi with inset showing the location and catchment of the lake. Note: Monitoring at Site L1 was discontinued in 2010 due to the riverine nature of the lake at this northern location.

2.2 Physicochemical monitoring

At each site, a depth profile is collected measuring temperature and dissolved oxygen. On all sampling occasions, water samples are collected using a grab sample to reflect conditions at the surface and using a Van Dorn sampler at points in the water column to understand conditions in the epilimnion and hypolimnion. In February and March (under targeted stratified conditions), additional water samples are collected near the base of the water column to assess the impact of anoxia at the sediment-water interface.

Table 3 Physicochemical parameters monitored at each sampling depth in Lake Rotorangi

Parameter	Units	Surface	Epilimnion	Hypolimnion	Lower hypolimnion (Lake benthos)[1]
Black disc transparency	m	x			
Secchi disc transparency	m	x			
pH	pH units	x	x	x	x
Conductivity	µS/cm	x	x	x	
Turbidity	FNU	x	x	x	x
Suspended solids	g m^{-3}	x	x	x	
E. coli	MPN/100mL	x			
Dissolved reactive phosphorus (DRP)	g m^{-3} P		x	x	x
Total phosphorus (TP)	g m^{-3} P		x	x	x
Ammoniacal nitrogen	g m^{-3} N		x	x	x
Nitrite nitrogen	g m^{-3} N		x	x	
Nitrate nitrogen	g m^{-3} N		x	x	
Nitrate and nitrite nitrogen	g m^{-3} N		x	x	x
Total Kjeldahl nitrogen	g m^{-3} N		x	x	
Total nitrogen (TN)	g m^{-3} N		x	x	

[1] Sampled in late summer and early autumn only

Sampling of the photic zone is undertaken in conjunction with physicochemical monitoring. A depth-integrated sample is collected and analysed for chlorophyll *a (*chl *a)*, and a sub-sample is used to identify the phytoplankton species present.

Samples are collected in accordance with the National Environmental Monitoring Standard (NEMS) for discrete lake water quality data (NEMS 2019).

2.3 Biological monitoring

A macrophyte survey is also undertaken triennially in autumn and was completed in the 2023/24 monitoring year.

2.4 Statistical analyses

This report provides a summary of the key results and analyses described below. A full copy of monitoring results can be provided by Council upon request.

2.4.1 Trophic level index (TLI)

The trophic level index (TLI) is calculated for the lake as well as for individual sites. The equations used are consistent with Burns et al. (2000). For this equation, four parameters are used (chlorophyll *a*, Secchi disk depth, total phosphorus and total nitrogen). Although total phosphorus and total nitrogen were measured throughout the water column, only the epilimnion was used for all TLI calculations in this report. This differed from past reports which used both the epilimnion and hypolimnion during unstratified periods.

This deviation from past methods was in part due to missing depth profiles being unable to determine if a lake was stratified or not during some sampling occasions. Concentrations of total phosphorus and total nitrogen in the epilimnion were comparable to those in the hypolimnion while the lake was observed as being unstratified during the monitoring period. Therefore, this difference in method should not result in any significant changes to the calculated TLI. Annual average values of the four parameters used are calculated, and are then input into these equations to calculate the four components of the TLI as follows:

$TLc = 2.22 + 2.54 \log (\text{Chl } a)$

$TLs = 5.10 + 2.27 \log ((1/\text{Secchi}) - (1/40))$

$TLp = 0.218 + 2.92 \log (TP)$

$TLn = -3.61 + 3.01 \log (TN)$

These four component values are then averaged to obtain the overall TLI. The results of the trophic index will determine the lake trophic status (Table 4). Table 4 also shows how different values of the trophic level components (chlorophyll *a*, Secchi depth, total phosphorus, and total nitrogen) would be classified.

Table 4 Lake status, trophic level and the different contributing parameters (adapted from Burns et al. (2000))

Lake status	Trophic level	Chl *a* (mg/m^3)	Secchi depth (m)	Total phosphorus (mg/m^3)	Total nitrogen (mg/m^3)
Ultra microtrophic	0 – 1	0.13 – 0.33	25 – 33	0.84 – 1.8	16 – 34
Microtrophic	1 – 2	0.33 – 0.82	15 – 25	1.8 – 4.1	34 – 73
Oligotrophic	2 – 3	0.82 – 2	7 – 15	4.1 – 9	73 – 157
Mesotrophic	3 – 4	2 – 5	2.8 – 7	9 – 20	157 – 337
Eutrophic	4 – 5	5 – 12	1.1 – 2.8	20 – 43	337 – 725
Supertrophic	5 – 6	12 – 31	0.4 – 1.1	43 – 96	725 – 1558
Hypertrophic	6 – 7	>31	<0.4	>96	>1558

2.4.2 Trend analyses

In this report, left censored data has been replaced with imputed values using regression on order statistics (ROS). This method fits a distribution to the non-censored values in the data record and uses the resulting model to impute replacement values for the censored data. The resulting calculated summary statistics and graphs are more robust than those used in reports prior to the 2021 report (Taranaki Regional Council 2021a), where summary statistics were biased by censored data being replaced with a value equal to half the censor limit.

Trend analyses were carried out using the LWP-Trends library R package (version 1901), developed by Land Water People Ltd. (Snelder & Fraser 2019). The methods employed have the primary purpose of establishing the direction and rate of any trend, along with a measure of the uncertainty in the result. The use of the LWP-Trends package represents a major change in trend analysis methodology compared to the Council's SoE reports prior to 2021, in part due to different methods used in the past, but also due to a recent conceptual shift in how to assess confidence in trend analysis results (Greenland et al. 2016, McBride 2019, Helsel et al. 2020).

As a first step in the trend analysis, a visual inspection of the raw time-series data is undertaken, giving a view of the proportion and temporal distribution of censored data. A Kruskal-Wallis test, using a threshold of $\alpha=0.05$, is employed to determine whether data is seasonal or not over the four separate annual samplings.

Depending on the result of the seasonality test, a non-parametric Mann-Kendall or seasonal Kendall test is used to determine the direction of a monotonic trend through the time-series data. Trend rate and the confidence in trend rate are evaluated using Sen-slope regression of observations against time. This is a non-parametric regression procedure, where the Sen-slope estimate (SSE) is taken as the median of all possible inter-observation slopes (Hirsch et al. 1982). In calculating the Kendall S statistic, censored data are dealt with as robustly as possible, following the methods of Helsel (2011), this allows inter-observation increases and decreases to be identified whenever possible (Snelder and Fraser 2019). In calculating the SSE, censored data are replaced by a value 0.5 times the highest common censor limit. While this biases inter-observation slopes associated with censored data, in most cases with a small proportion of censored data, the median slope will be unaffected. In general, when the SSE is affected by censored data, this usually indicates that the trend rate is smaller than can be detected. Trends noted as being affected by censored data are critically analysed to assess if the resulting statistics are meaningful or not.

While past trend analysis has reported on the 'significance' of any reported trend, in this report the assessment of confidence in a trend direction moves away from the traditional null hypothesis significance testing (NHST) approach and instead follows the recommended credible interval assessment method of McBride (2019). As a result of this change, the confidence in the reported trend direction (ranging from 50 to 100%) is now categorised as in Table 5.

Table 5 Confidence categorisation for trend direction results

Confidence Category	Confidence in reported trend direction
Very Likely Improving	90 – 100%
Likely Improving	67 – 90%
Indeterminate	50 – 67%
Likely Degrading	67 – 90%
Very Likely Degrading	90 – 100%

In the case of parameters that are sampled at multiple depths within the lake, trend analysis has been carried out on the data from the epilimnion. Differences in the water chemistry between the epilimnion and hypolimnion may mask any trends present in either layer. Furthermore, the magnitude of the seasonal change in the hypolimnion is greater for many parameters, and the magnitude of seasonal variation may hinder the ability to detect the trend over time. The use of epilimnion data in trend analysis is consistent with national reporting (Larned et al. 2015).

Trend analyses were performed on both sites, as well for the lake overall. Although it is typical to report statistical analyses for a lake holistically, the riverine nature of Lake Rotorangi means that there are differences in water chemistry between the mid and lower lake sites. Therefore, the trend analysis for the whole lake should be interpreted with caution. Additionally, trends were determined using the raw data, from the respective site, or in the case of the whole lake, the raw data from both sites. Although samples began in 1990 for most parameters, these were often missing certain seasons and therefore these years were omitted for trend analyses.

2.4.3 Attribute state and the National Objectives Framework

With some of the parameters, including ammoniacal nitrogen (epilimnion), total nitrogen (epilimnion), chlorophyll *a* (photic zone) and total phosphorus (epilimnion), we can assess the results against the numeric attribute state included in the National Objectives Framework (NOF), as part of the National Policy Statement for Freshwater Management 2020 (NPS-FM). Generally, this uses annual medians, however, due to this programme's quarterly sampling design, this data is limited and instead measurements over three years have been used. In this report we also assess numeric attribute states for five years of *E. coli* data and dissolved oxygen annual minima. It is important to note that *E. coli* measurements should be taken once a month as per the NPS-FM, however, the Council takes four samples a year, therefore analyses are completed with a limited sample size.

3. Results

3.1 General observations

General observations made on each sampling occasion during the period under review are presented in Table 6.

Table 6 Observations at Lake Rotorangi monitoring sites during sampling in 2021-2024

Date	Lake level (m asl)	Weather	Wind		Lake appearance	
			LRT000300	LRT000450	LRT000300	LRT000450
21 Oct 2021	76.95	Overcast; rain in last week	No wind	No wind	Slightly turbid, green-brown; flat	Slightly turbid, green-brown; flat
21 Feb 2022	77.35	Heavy rain week prior, warm, calm, dry	No wind	Light breeze	Turbid, brown, flat	Turbid, brown; flat
21 Mar 2022	76.47	Moderate rain, heavy rain overnight, overcast	Light breeze	Light breeze	Clear, dark green; rippled	Slightly turbid, brown; rippled
29 Jun 2022	76.95	Overcast, drizzle	No wind	No wind	Slightly turbid, brown-green; surface flat	turbid, brown; flat
19 Oct 2022	75.57	Light showers and light wind	No wind	Light breeze	Turbid, brown, flat	Slightly turbid, brown-green, rippled
20 Feb 2023	-	Fine	No wind	No wind	Turbid, brown, flat	Turbid, brown, rippled
22 March 2023	-	Drizzle, overcast	No wind	No wind	Slightly turbid, green, flat	Turbid, Green, flat
22 June 2023	76.23	Overcast	Light breeze	No wind	Slightly turbid, brown, rippled	Slightly turbid, brown, flat
25 October 2023	76.53	Overcast, sun showers,	Moderate wind	mixture of wind then no wind	Slightly turbid, green brown, choppy	Clear, brown, rippled
21 February 2024	76.50	Fine, overcast	No wind	No wind	Clear, green, flat	Clear, green, flat
27 March 2024	-	Fine	Light breeze	Light Breeze	Clear, green, rippled	Clear, green, rippled,
19 June 2024	-	Fine, heavy rain two days prior	Light to moderate breeze	Light to moderate breeze	Turbid, rippled	Clear, brown/green, rippled

3.2 Lake stratification

In this monitoring programme, thermal stratification events have previously been defined by a difference in lake water temperature of 3°C or greater with depth through the water column. Here, this 3°C criteria is use as a guideline, rather than a strict limit, given the variability in stratification patterns that can occur. This is consistent with the protocol included in Burns et al (1999). Complete depth profile charts, including temperature and dissolved oxygen measurements, are included in Appendix II.

Throughout the reporting period, there was a range of different stratification profiles seen (Appendix II). There was weak stratification at both sites during all three October surveys. Lake bottom waters were deoxygenated but not anoxic (defined as dissolved oxygen (DO) concentrations less than 0.5g/m^3) at both sites in 2021 (0.65g/m^3 and 1.04g/m^3, respectively). In 2022, anoxic conditions were observed at the lake-bottom at both monitoring sites. In 2023, lake-bottom waters were more oxygenated, with a 5.76g/m^3 DO concentration recorded at LRT000300 and 4.28g/m^3 recorded at LRT000450.

Stratification was observed during all three February sampling surveys at both sites. Anoxia at the lake bottom was observed on every occasion that the measurements were taken.

In March 2023, both sites were stratified with anoxic lake-bottom waters. There was no depth profile taken in 2022 or 2024 due to equipment issues.

In June 2022, both sites were stratified, with anoxia observed at the lake bottom at site LRT000450 but not LRT000300. In June 2024, both sites were stratified, though the differences in water temperatures between layers were relatively small. Both sites were anoxic at the lake bottom during this survey.

For both sites, over the past three monitoring years, the annual minima mid-hypolimnion and lake-bottom dissolved oxygen concentrations were below the national bottom line (band D) that is prescribed in NOF (Table 7).

Table 7 Minimum dissolved oxygen concentrations (g/m^3) in Lake Rotorangi assessed against National Objective Framework attribute bands (NPS-FM, 2020)

Year	Site	Minimum	Layer
2021/22	LRT000300	0.38	Lake-bottom
	LRT000450	0.00	
	LRT000300	0.00	Mid-hypolimnion
	LRT000450	0.00	
2022/23	LRT000300	0.02	Lake-bottom
	LRT000450	0.00	
	LRT000300	0.00	Mid-hypolimnion
	LRT000450	0.00	
2023/24	LRT000300	0.00	Lake-bottom
	LRT000450	0.00	
	LRT000300	0.00	Mid-hypolimnion
	LRT000450	0.00	

Note: (A = blue, B = green, C = yellow, D = red)

Anoxia in the lower hypolimnion means the biogeochemical conditions are likely to cause release of nutrients from lakebed sediment into water column during periods of stratification. In recognition of this, water samples have been collected from the bottom of the water column and analysed for nutrient concentrations during stratified periods since 1996. Over this time period, the data have shown a small increase in ammoniacal nitrogen and a very small decrease in nitrate nitrogen near the lakebed compared to in the hypolimnetic water column. This change may result from the reduction of nitrate to ammonia in the water column or the release of ammonia from anoxic sediments.

Concentrations of ammoniacal nitrogen in the water column near the lakebed were elevated on several occasions (Figure 2). At LRT000300, there were three sampling occasions where ammoniacal nitrogen concentrations were more than double those observed in the hypolimnion. However, whilst these concentrations were elevated in relation to those in the hypolimnion, they remained lower than the long-term median concentration. At LRT000450, ammoniacal nitrogen concentrations were markedly elevated compared to the hypolimnion in February and March 2022. In March 2022, this result was also elevated compared to the long-term median.

The differences in concentrations of nitrate/nitrite and DRP between the two levels in the lake water column were much less pronounced. At LRT000300, concentrations of DRP in the hypolimnion were approximately double those observed in the water column near the lakebed.

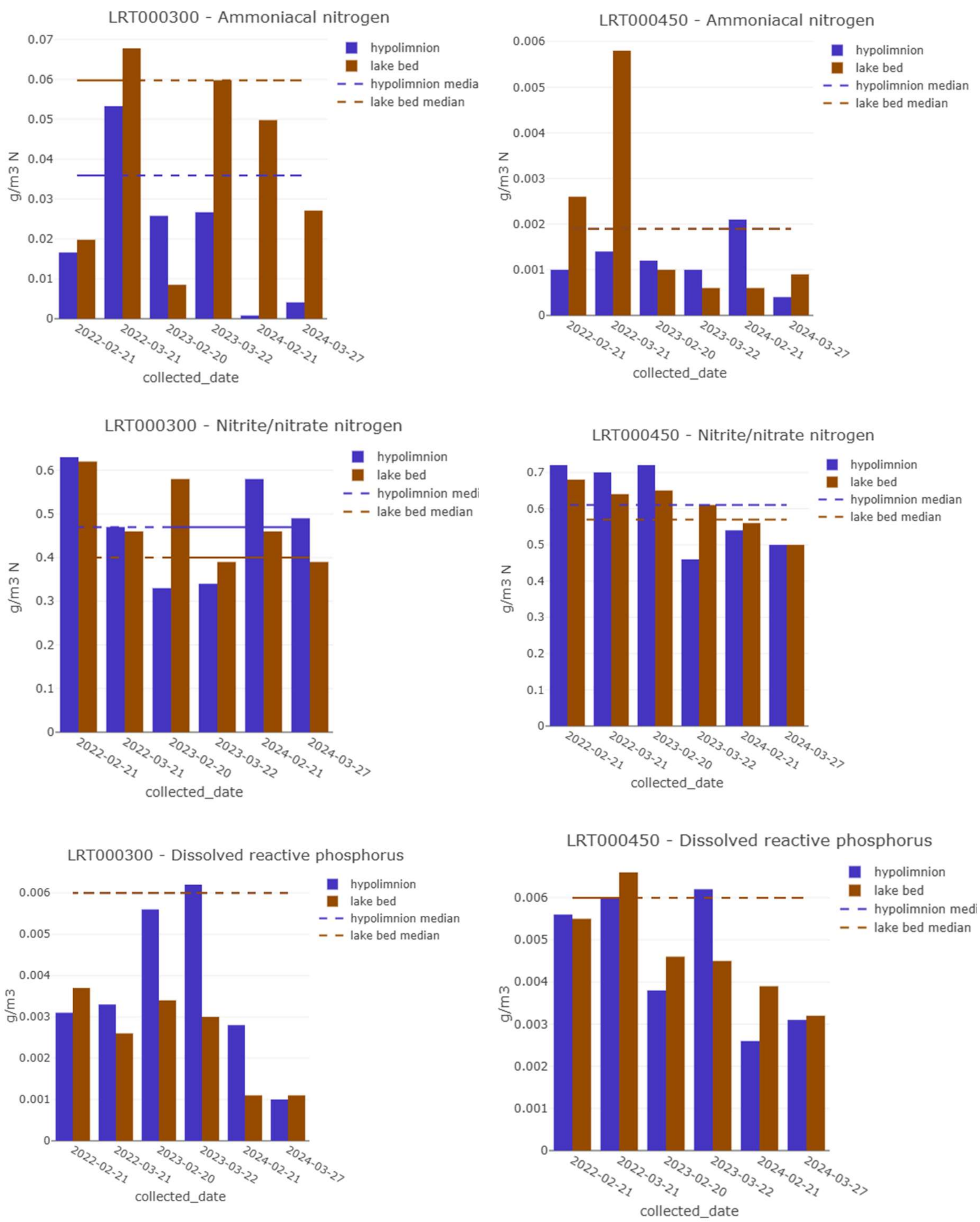

Figure 2 Concentrations of selected nutrients in the water column near the lakebed and in the hypolimnion in February and March (2021-2024)

3.3 Lake water quality

3.3.1 Nitrogen

Annual median concentrations of total nitrogen were variable over the three years from 2021 to 2024 (Figure 3, Figure 4 and Appendix III).

In 2021/22, annual median concentrations in both the epilimnion and hypolimnion were particularly high compared to the respective historical medians at both sites. At site LRT000300, the annual median concentration in the hypolimnion was 0.98g/m^3, which is the highest ever recorded (slightly greater than the highest annual median which was recorded in 2003/04). The annual median concentration in the epilimnion was 0.93g/m^3, which is comparable, but slightly lower than the highest annual median recorded in 2003/04. At site LRT000450, the annual median concentration in the epilimnion was also the highest recorded (0.88g/m^3). In 2022/23, annual median concentrations in both the epilimnion and hypolimnion were generally comparable to the historic medians at both sites. In 2023/24, the annual medians at both sites for both the epilimnion and hypolimnion were lower than their respective historical medians. For the hypolimnion, this annual median concentration was the lowest ever recorded for that site and sampling depth (0.65g/m^3). At site LRT000450, the annual median concentration in the epilimnion was also the lowest recorded (0.41g/m^3).

The median total nitrogen concentrations at sites LRT00300 and LRT00450 over the past three years of monitoring were 665 and 655mg/m^3 respectively, both of which fall into band C under the NOF framework (Table 8).

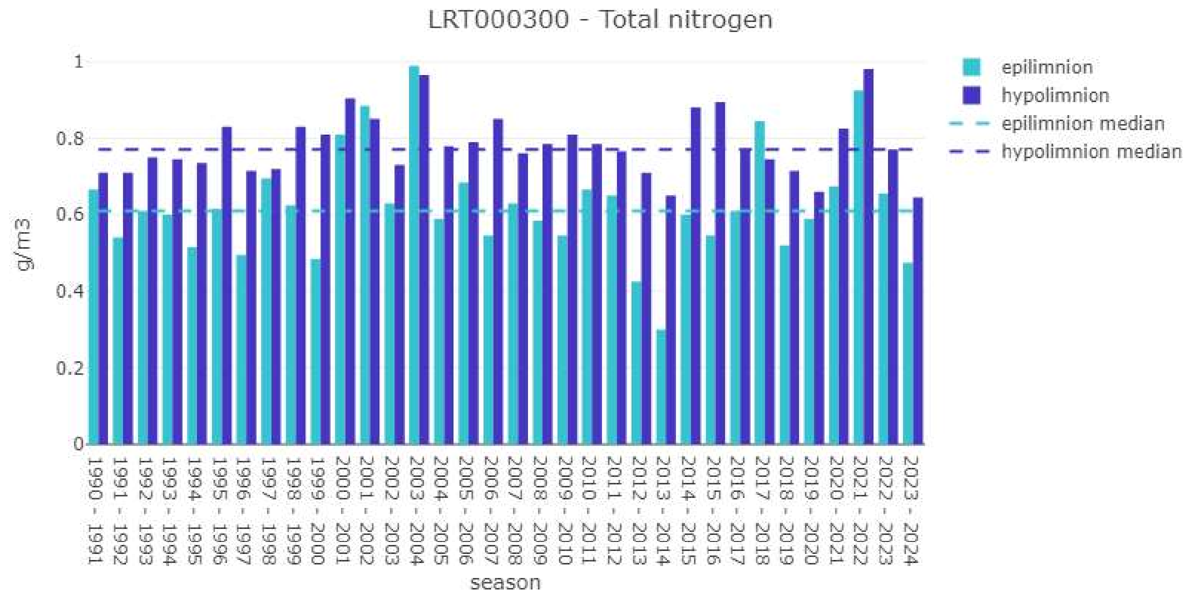

Figure 3 Annual median total nitrogen concentrations at LRT00300 since 1990

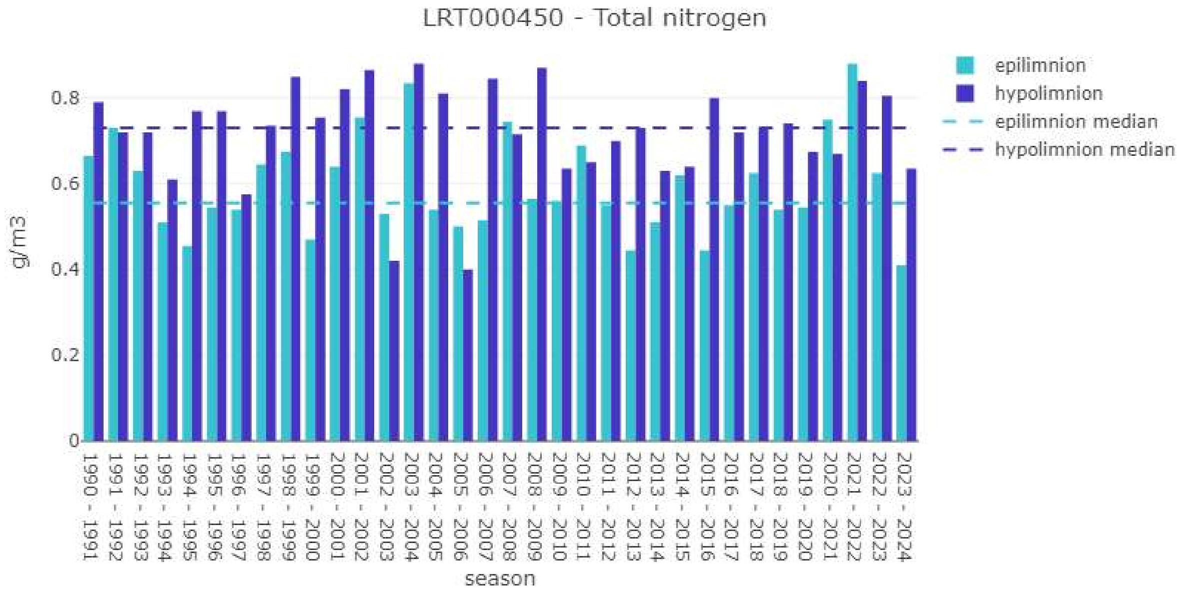

Figure 4 Annual median total nitrogen concentrations at LRT00450 since 1990

Annual median concentrations of nitrite/nitrate in the epilimnion and hypolimnion were above their respective historic medians at both sites in the 2021/22 monitoring year, equalling the highest previously recorded in the epilimnion (Figure 5, Figure 6 and Appendix III). In 2022/23, annual medians were comparable to historic medians. In 2023/24 annual medians were comparable to, or below, historic medians.

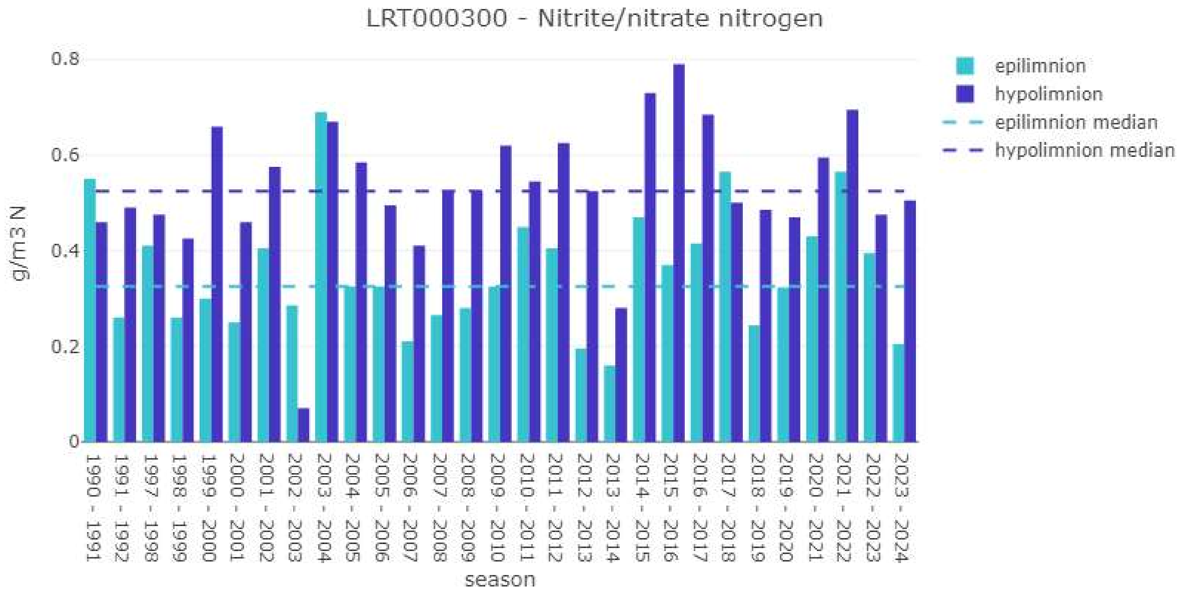

Figure 5 Annual median nitrite/nitrate concentrations at LRT00300 since 1990

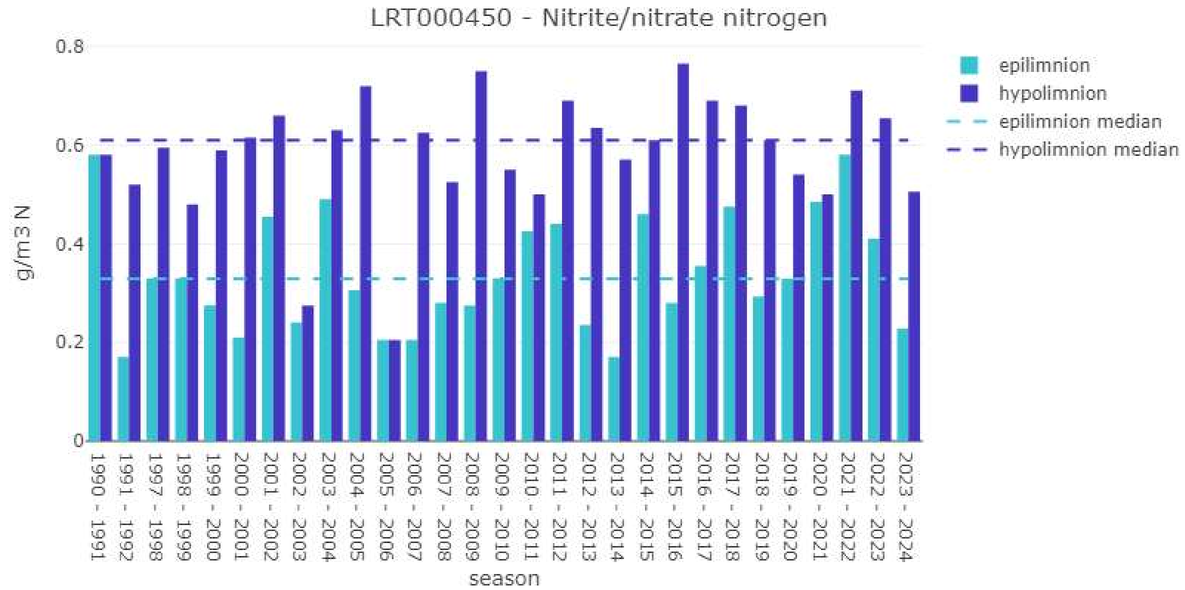

Figure 6 Annual median nitrite/nitrate concentrations at LRT00450 since 1990

Annual median concentrations for ammoniacal nitrogen were comparable to, or below, the respective historic medians for both sites and sampling depths (Figure 7, Figure 8 and Appendix III).

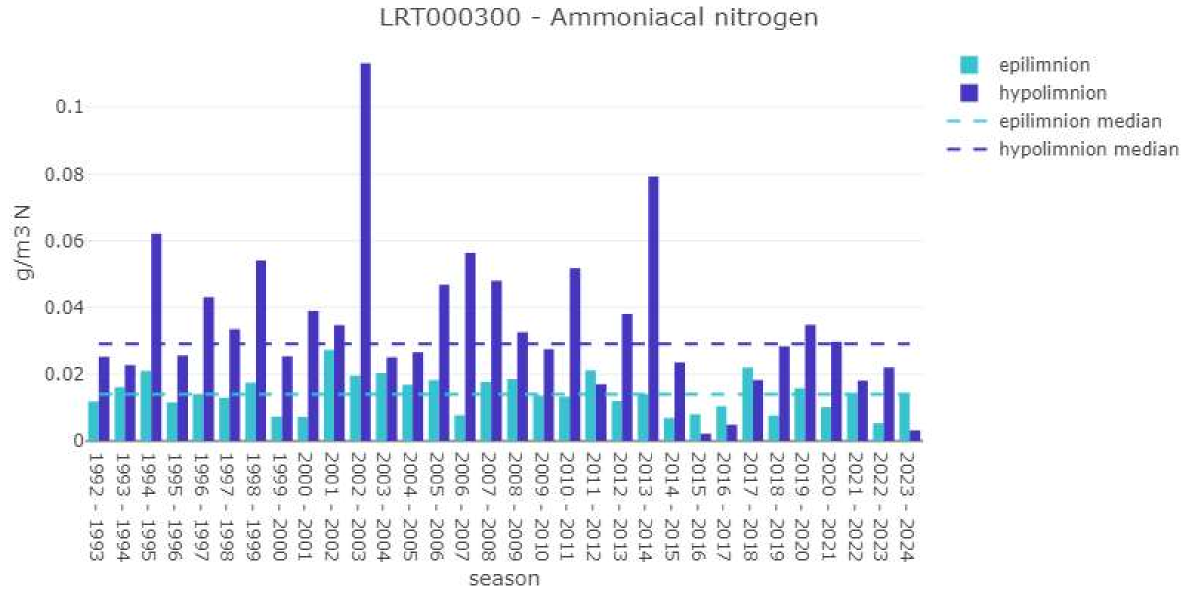

Figure 7 Annual median ammoniacal nitrogen concentrations at LRT00300 since 1992

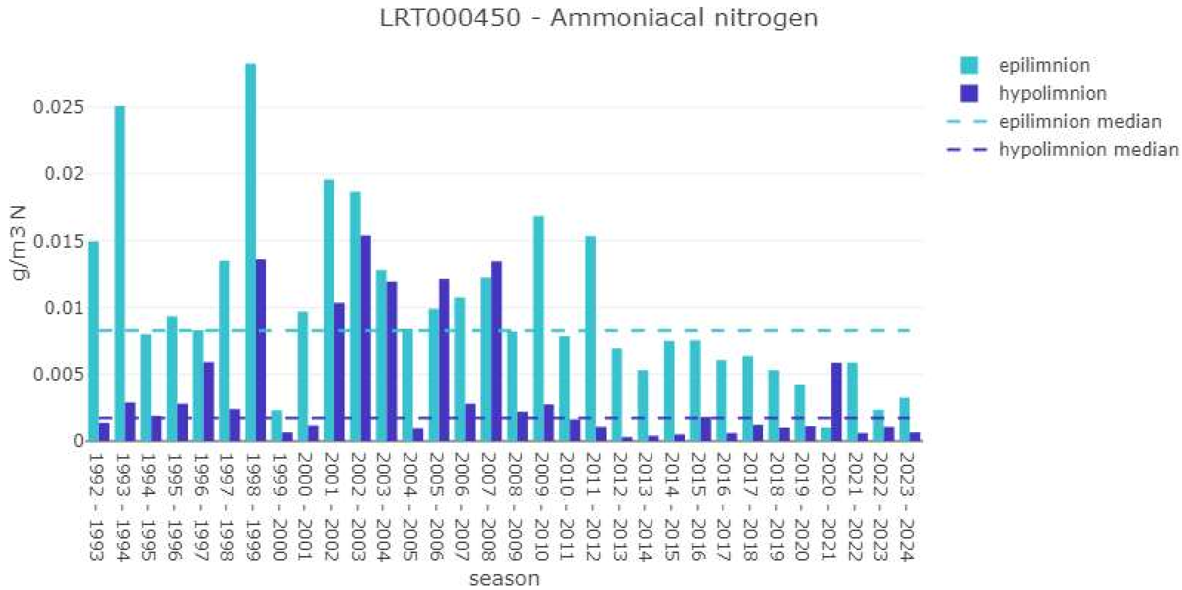

Figure 8 Annual median ammoniacal nitrogen concentrations at LRT00450 since 1992

The three-year ammoniacal nitrogen median and 95th percentile concentrations were in the NOF band A for both sites (Table 8).

Table 8 Median ammoniacal nitrogen and total nitrogen concentrations assessed against the National Objective Framework attribute bands (NPS-FM, 2020)

Parameter (unit)	Site	Median	95th percentile
Ammoniacal nitrogen (mg/L)	LRT00E300	0.022	0.04
	LRT00E450	0.007	0.02
Total Nitrogen (mg/m^3)	LRT00E300	665	
	LRT00E450	655	

Note: (A = blue, B = green, C = yellow, D = red)

3.3.2 Phosphorous

The annual median concentrations for total phosphorous in 2021/22 and 2022/23 were generally comparable to, or slightly higher than the historic medians at both monitoring sites and sampling depths (Figure 9, Figure 10 and Appendix III). In 2023/24, the annual median concentration from epilimnion samples at site LRT000300 was comparable to the historic median, whereas the annual median concentrations in the hypolimnion at LRT000300 and both the epilimnion and hypolimnion at LRT000450 were all equal to, or lower than, the lowest annual medians on record previously (0.011, 0.010, and 0.008g/m^3, respectively).

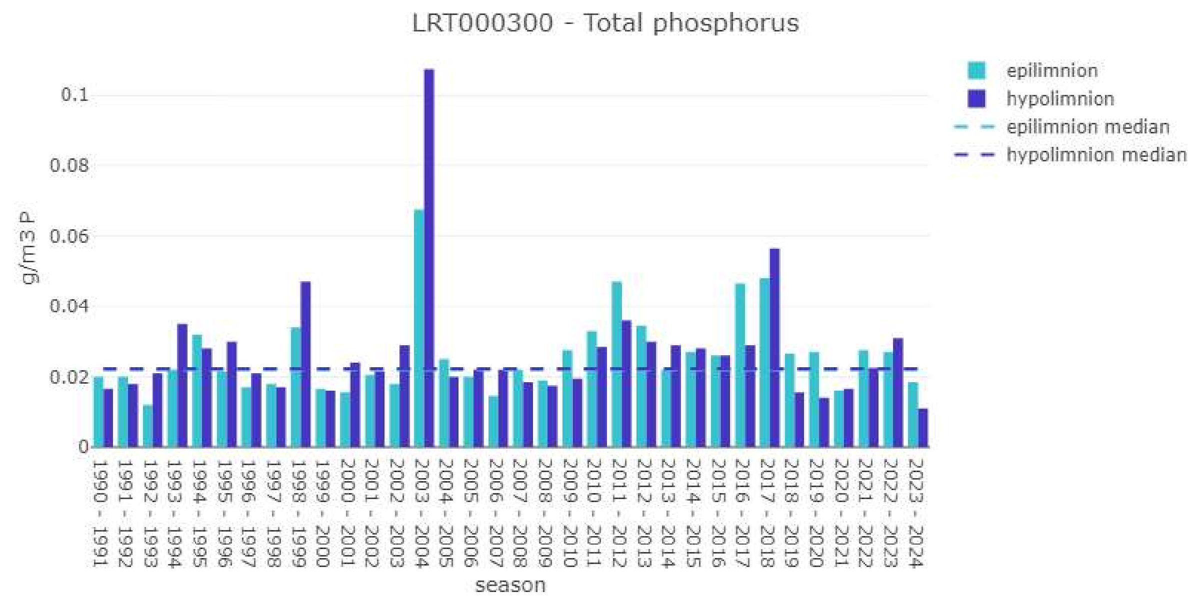

Figure 9 Annual median total phosphorus concentrations LRT00300 since 1990

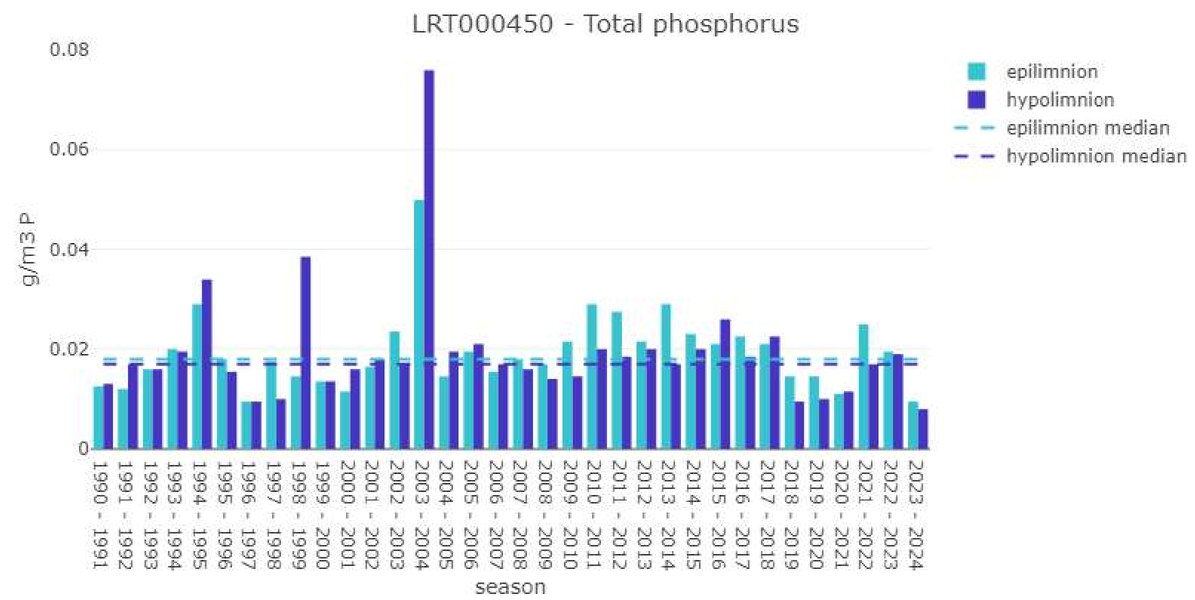

Figure 10 Annual median total phosphorus concentrations LRT00450 since 1990

During the period under review, total phosphorous concentrations were in NOF band C for LRT000300 and band B for LRT000450 (Table 9).

Table 9 Median total phosphorus concentrations assessed against the National Objective Framework attribute bands (NPS-FM, 2020)

Parameter (unit)	Site	Median
Total Phosphorus (mg/m3)	LRT000300	25
	LRT000450	18

Note: (A = blue, B = green, C = yellow, D = red)

At LRT000300, annual median concentrations of dissolved reactive phosphorous were lower than the historic median concentrations for their respective sampling depths on all three years of this reporting period (Figure 11 and Appendix III). These differences were most pronounced in the hypolimnion in 2021/22 and 2023/24, and in the epilimnion in 2022/23 and 2023/24. The 2023/24 annual median concentration in the hypolimnion was the lowest recorded for that site and sampling depth (0.0026g/m^3).

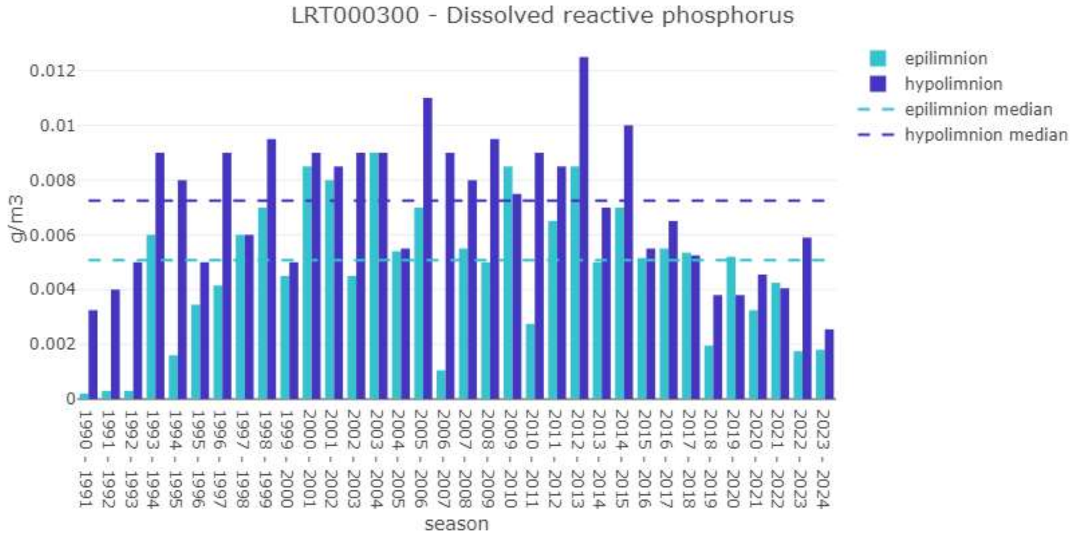

Figure 11 Annual median dissolved reactive phosphorus concentrations at LRT00300 since 1990

At LRT000450, the 2021/22 annual median concentrations for DRP were comparable to historic medians at both sampling depths (Figure 12 and Appendix III). Annual medians in the epilimnion were lower than the historic median in 2022/23 and equalled the lowest annual median on record in 2023/24 (0.0002g/m^3, also recorded in 1991/92). In the hypolimnion, annual median concentrations were comparable to, but below the historic median in 2022/23, and approximately half the historic median concentration in 2023/24.

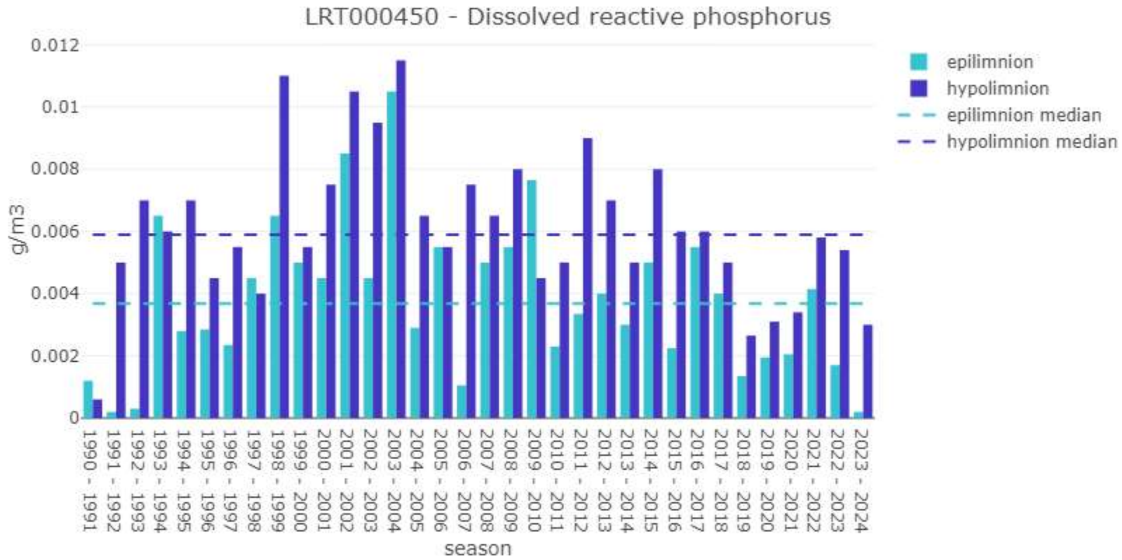

Figure 12 Annual median dissolved reactive phosphorus concentrations at LRT00450 since 1990

3.3.3 Secchi disc depth

At LRT000300, the annual median Secchi disc depth was 1.46m, 1.15m, and 2.48m in 2021/22, 2022/23 and 2023/24, respectively (Figure 13 and Appendix III). Compared to the historic median depth of 2.54m, these measurements were much lower in 2021/22 and 2022/23, and very similar in 2023/24.

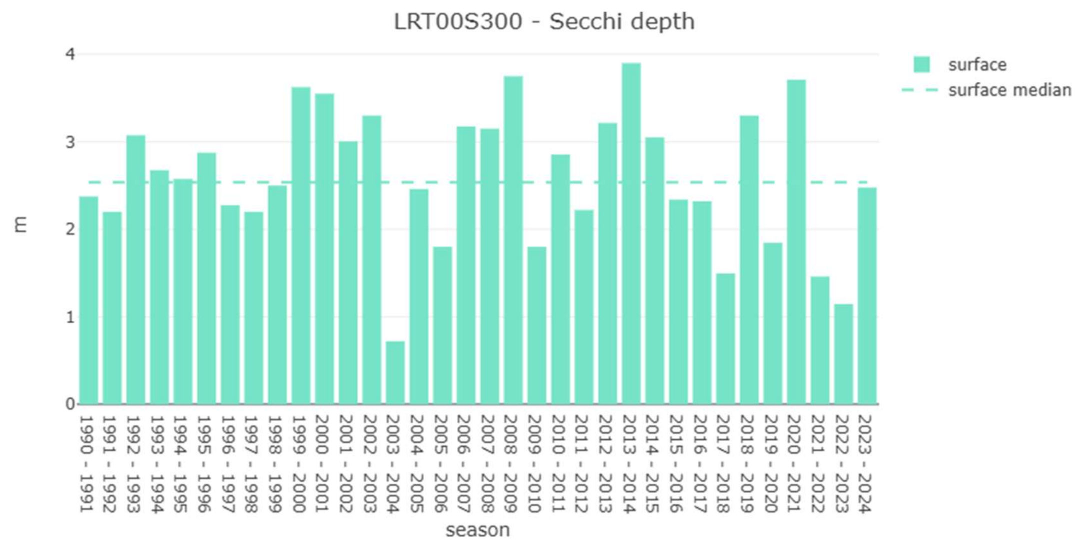

Figure 13 Annual median Secchi disc depth at site LRT00300 since 1990

At LRT000450, the annual median Secchi disc depth was 1.40m, 1.73m, and 3.35m in 2021/22, 2022/23 and 2023/24, respectively (Figure 14 and Appendix III). Compared to the historic median depth of 3.20m, these measurements were much lower in 2021/22 and 2022/23, and very similar in 2023/24.

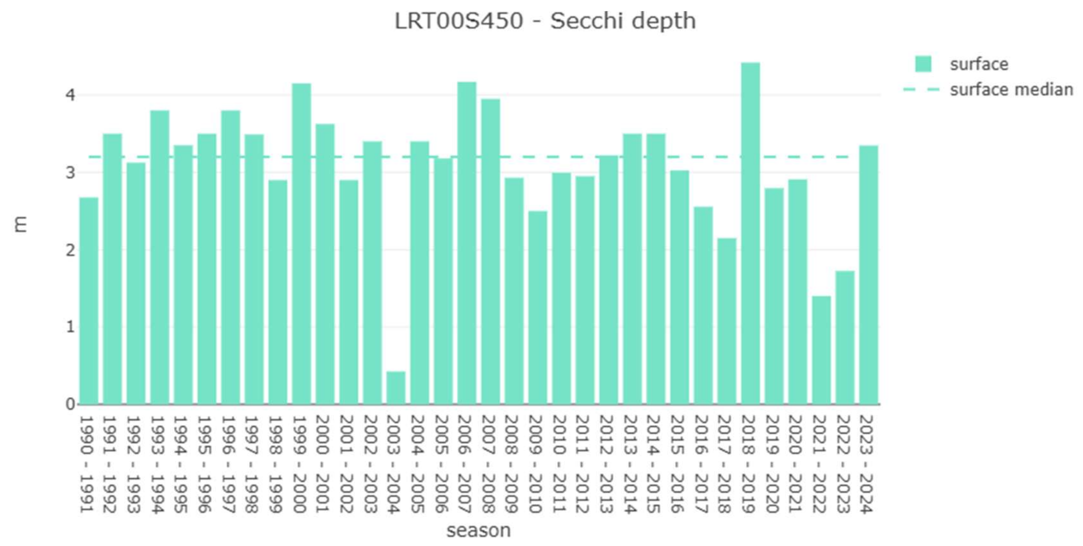

Figure 14 Annual median Secchi disc depth at site LRT00450 since 1990

3.3.4 Chlorophyll *a* (phytoplankton)

At site LRT00P300, in 2021/22 and 2022/23, annual median chlorophyll *a* concentrations were above the historic median of 2.48mg/m^3 (Figure 15 and Appendix III). The annual median in 2021/22 was the highest ever recorded at this site (5.57mg/m^3). In contrast, the 2023/24 annual median at site LRT00P300 was the lowest annual median recorded at this site (1.05mg/m^3).

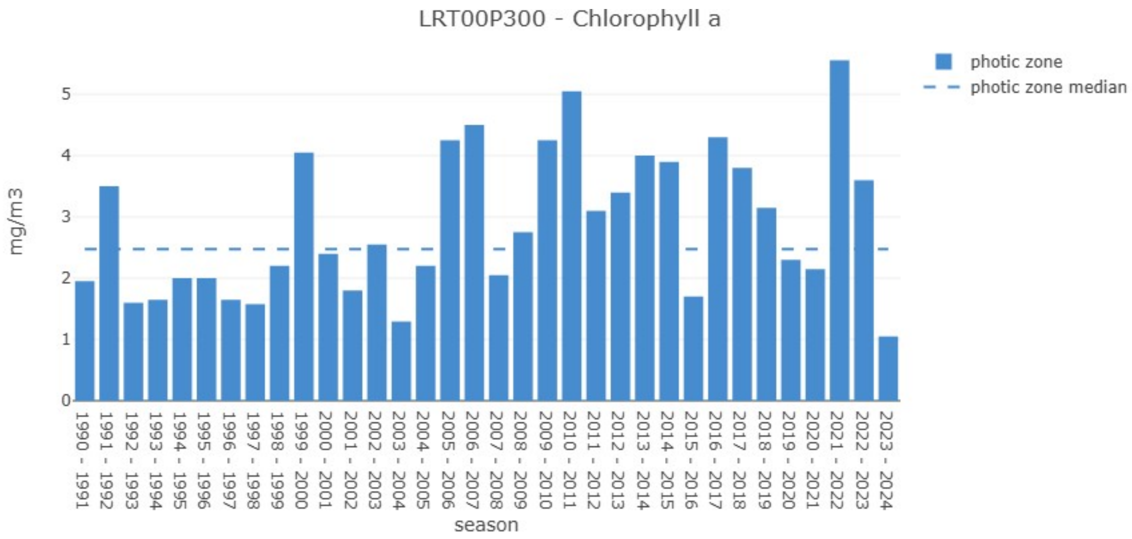

Figure 15 Annual median chlorophyll *a* concentrations at site LRT00P300 since 1990

At site LRT00P450 in 2021/22 and 2022/23, the annual median concentrations were comparable to the historic median (2.23mg/m^3, Figure 16 and Appendix III). In contrast, the annual median concentration in 2023/24 was the second lowest on record (1.35mg/m^3).

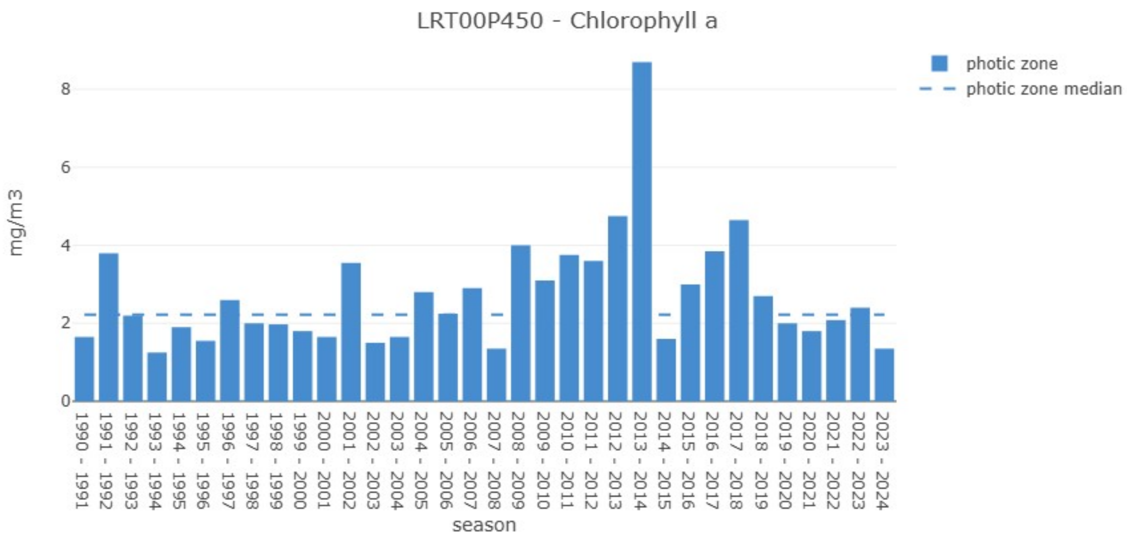

Figure 16 Annual median chlorophyll *a* concentrations at site LRT00P450 since 1990

Assessment of chlorophyll *a* concentrations in Lake Rotorangi against the NOF phytoplankton attribute based on the three years of data from 2021 to 2024 places both sites in band A for median concentrations. For maximum chlorophyll *a* concentrations, site LRT00P300 is in band C and site LRT00P450 is in band B (Table 10).

Table 10 Chlorophyll *a* concentrations assessed against the National Objectives Framework attribute bands (NPS-FM, 2020)

Site	Median (mg/m^3)	Maximum (mg/m^3)
LRT00P300	1.3	38
LRT00P450	1.55	16.9

Note: (A = blue, B = green, C = yellow, D = red)

At site LRT00P300, the median phytoplankton taxonomic richness (number of species) was 9.5, 12, and 11.5 in the years 2021/22, 2022/23, and 2023/24, respectively (Figure 17). At site LRT00P450, the annual median taxonomic richness was 8.0, 5.5, and 10.5 in the years 2021/22, 2022/23, and 2023/24, respectively (Figure 18).

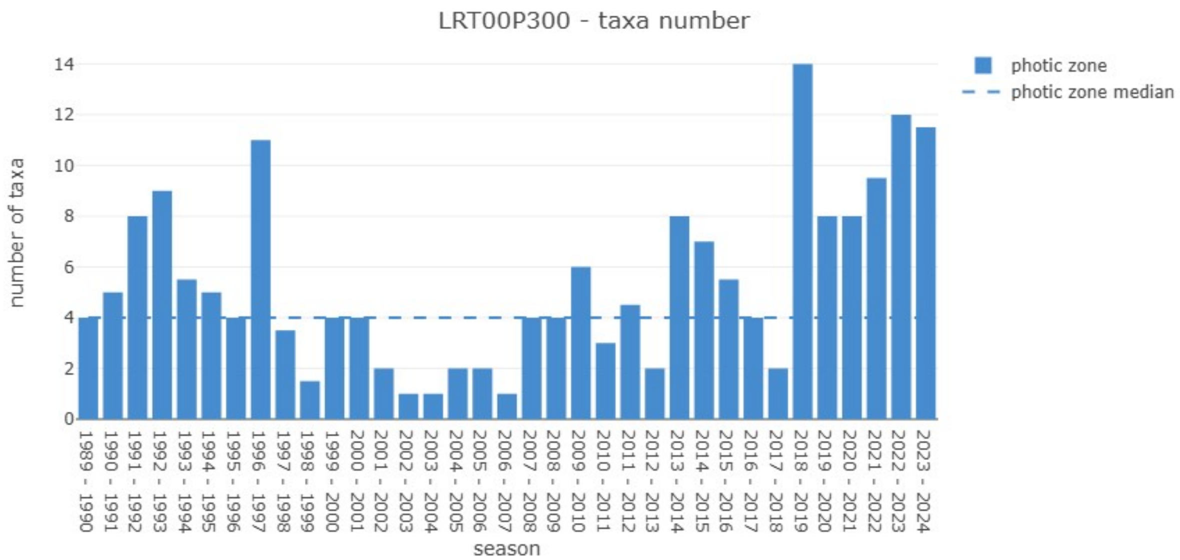

Figure 17 Annual median phytoplankton taxa richness at site LRT00P300 since 1989

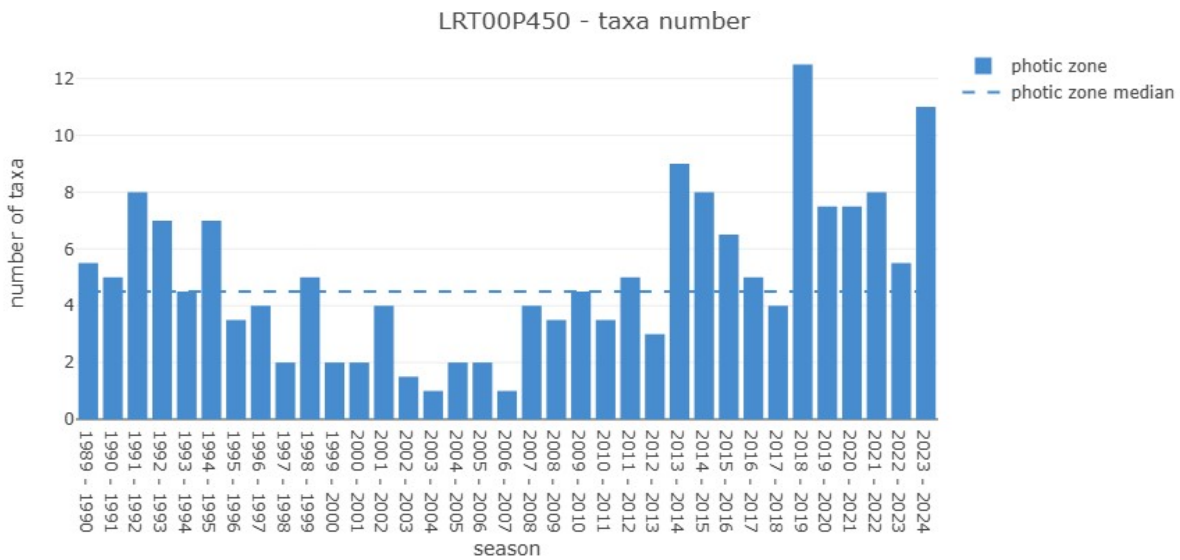

Figure 18 Annual median phytoplankton taxa richness at site LRT00P450 since 1989

3.3.5 Escherichia coli *(E. coli)*

At LRT000300, the annual median *E. coli* concentration was 26, 13 and 18 MPN/100 ml in 2021/22, 2022/23 and 2023/24, respectively (Figure 19 and Appendix III). These results were all similar to the historic median concentration for this site (21 MPN/100ml).

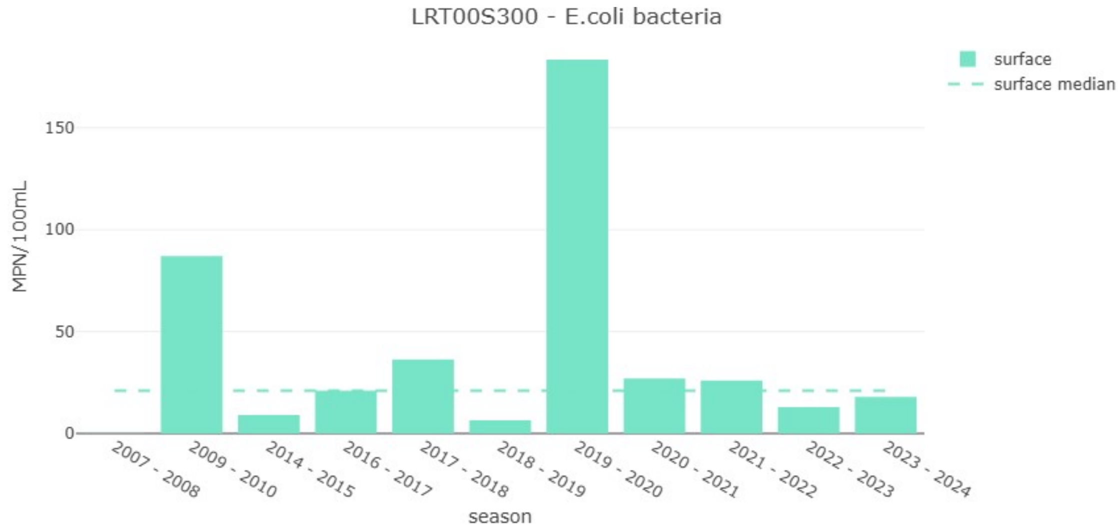

Figure 19 Annual median *E. coli* concentrations at site LRT00S300 since 2009

At LRT000450, the annual median *E. coli* concentration was 5, 9 and 2 MPN/100 ml in 2021/22, 2022/23 and 2023/24, respectively (Figure 20 and Appendix III). These results were all similar to the historic median concentration for this site (4 MPN/100ml). Overall, *E. coli* concentrations remained low at both sites during the monitoring period. The results reflected the long-term differences observed between sites, with concentration at LRT000450 lower than those at LRT000300.

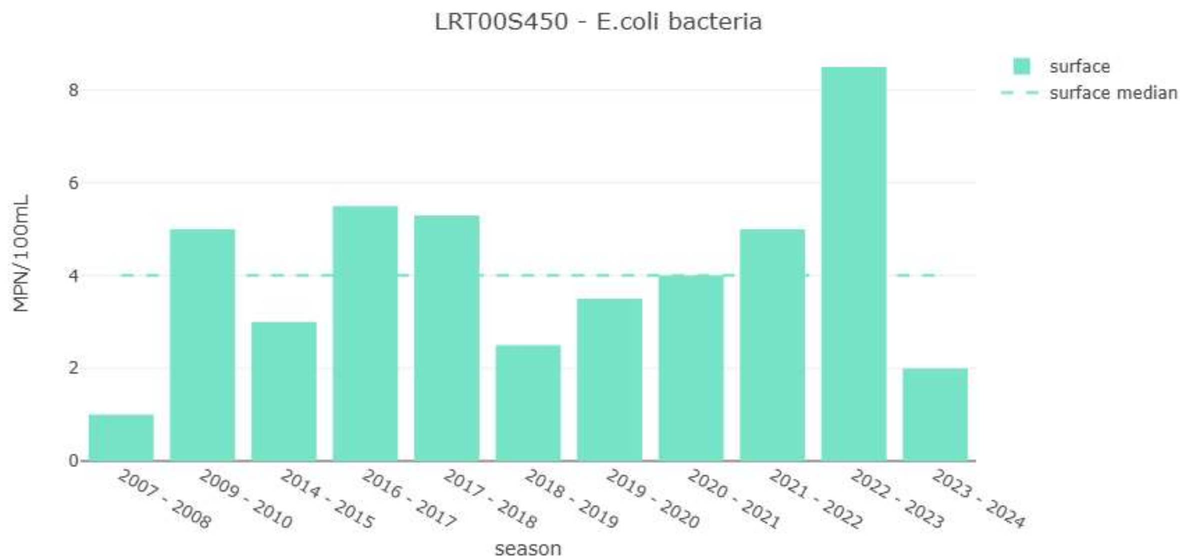

Figure 20 Annual median *E. coli* concentrations at site LRT00S450 since 2009

Assessment of *E. coli* concentrations in Lake Rotorangi against the NOF phytoplankton attribute based on the five years of data from 2019 to 2024 places both sites in band A for all four statistical criteria (Table 11)

Table 11 *E. coli* concentrations assessed against the National Objectives Framework attribute bands (NPS-FM, 2020)

Site	% exceedances over 540/100mL	% exceedances over 260/100mL	Median	95th percentile
LRT00S300	0	10.5	24	366.9
LRT00S450	0	0	3	23.1

Note: Colours indicate which band the numeric attributes fall within (A = blue, B = green, C = yellow, D = red).

3.4 Overall trophic state

The overall lake trophic level indices were 4.78, 4.34, and 3.60 for the monitoring years 2021/22, 2022/23 and 2023/24, respectively (Table 12). As such, the lake was classified as eutrophic in 2021/22 and 2022/23, but mesotrophic in 2023/24. These overall lake classifications were consistent for both monitoring sites.

When the individual components of trophic level are considered, in 2021/22, chlorophyll *a*, Secchi depth and total phosphorus concentrations were indicative of a eutrophic lake status, while total nitrogen concentrations were indicative of a supertrophic lake status. In 2022/23, Secchi depth, total nitrogen and total phosphorus concentrations were indicative of a eutrophic lake status, while chlorophyll *a* concentrations were indicative of a mesotrophic lake status. The individual components in 2023/24 varied. Chlorophyll *a* concentrations were indicative of an oligotrophic lake status, total nitrogen concentrations were indicative of a eutrophic lake status, while Secchi depth and total phosphorus concentrations were indicative of a mesotrophic lake status.

Table 12 Trophic level and values of key variables defining the trophic status of Lake Rotorangi from the previous three monitoring seasons, numbers based on Burns (1999)

Monitoring year	Trophic Level Components	LRT000300	LRT000450	Combined sites
2021/22	Overall trophic status	Eutrophic	Eutrophic	Eutrophic
	Trophic level	4.94 (E)	4.62 (E)	4.78 (E)
	Chlorophyll *a* (mg/m^3)	12.23 (S)	5.175 (E)	8.7 (E)
	Secchi depth (m)	1.49 (E)	1.56 (E)	1.53 (E)
	Total nitrogen (mg/m^3)	875 (S)	865 (S)	870 (S)
	Total phosphorus (mg/m^3)	38.75 (E)	30.75 (E)	34.75 (E)
2022/23	Overall trophic status	Eutrophic	Eutrophic	Eutrophic
	Trophic level	4.48 (E)	4.20 (E)	4.34 (E)
	Chlorophyll *a* (mg/m^3)	3.8 (M)	3.03 (M)	3.41 (M)
	Secchi depth (m)	1.11 (E)	1.84 (E)	1.47 (E)
	Total nitrogen (mg/m^3)	626.5 (E)	642.5 (E)	652.5 (E)
	Total phosphorus (mg/m^3)	26.5 (E)	21 (E)	23.75 (E)
2023/24	Overall trophic status	Mesotrophic	Mesotrophic	Mesotrophic
	Trophic level	3.80 (M)	3.40 (M)	3.60 (M)
	Chlorophyll *a* (mg/m^3)	1.58 (O)	1.33 (O)	1.45 (O)
	Secchi depth (m)	2.51 (E)	3.52 (M)	3.01 (M)
	Total nitrogen (mg/m^3)	467.5 (E)	425 (E)	446.25 (E)
	Total phosphorus (mg/m^3)	18.75 (M)	9 (M)	13.88 (M)

Note: Letters in brackets relate to the trophic status of each component; M=Mesotrophic, E=Eutrophic, S=Supertrophic

Over the entire monitoring record, the trophic level index at LRT000300 has ranged from 3.80 to 4.94, with an historic median of 4.17 (Figure 21 and Appendix III). The maximum and minimum results were both recorded during the monitoring period under review. In 2021/22, the trophic level index at this site was the highest ever recorded (4.94 TLI units). Conversely, in 2023/24, the trophic level index was the lowest ever recorded (3.80 TLI units.)

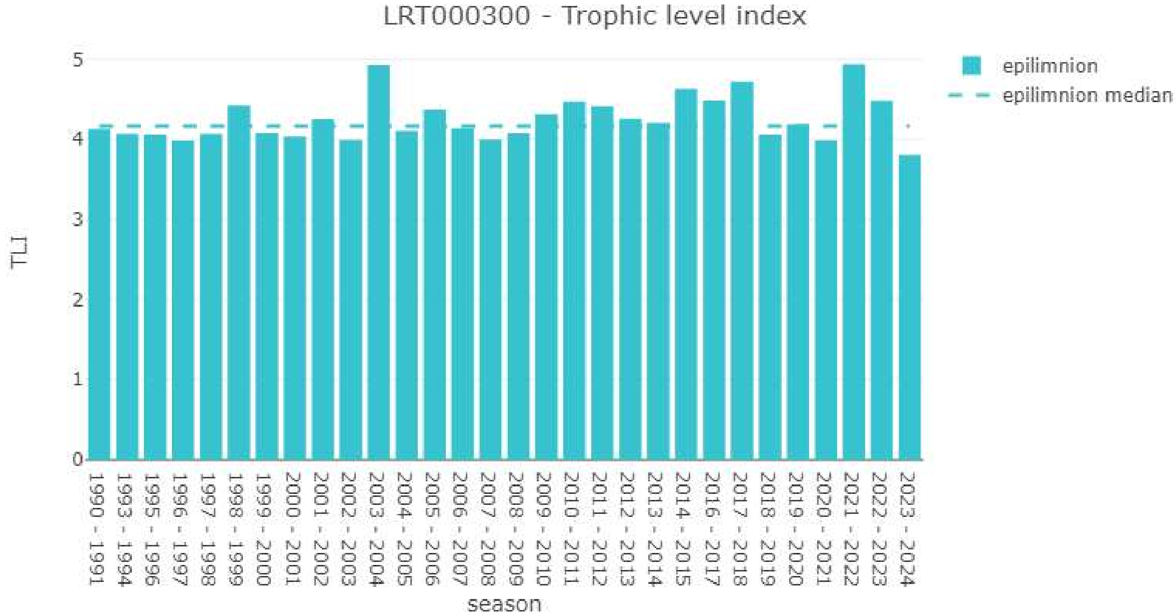

Figure 21 Annual trophic level index at site LRT000300 over the monitoring years since 1990

At LRT000450, the trophic level index over the entire monitoring record has ranged from 3.40 to 4.97, with an historic median of 3.98 (Figure 22 and Appendix III). While the two results from 2021/22 and 2022/23 were both above the historic median, the lowest ever result was recorded in 2023/24 (3.40).

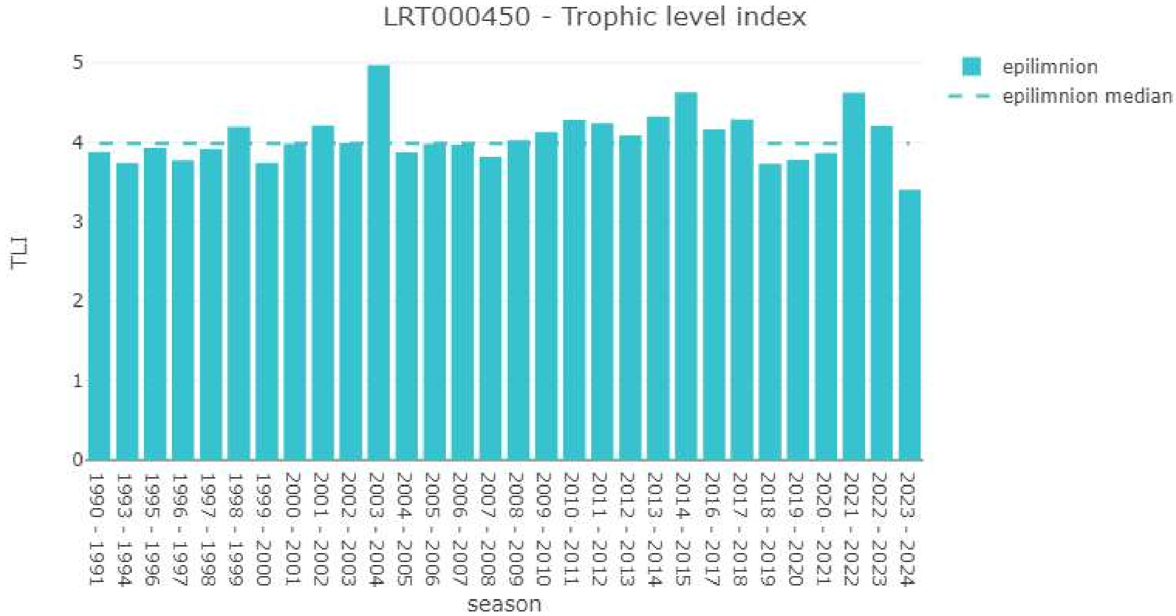

Figure 22 Annual trophic level index at site LRT000450 over the monitoring years since 1990

3.5 Autumn macrophyte survey

An autumn macrophyte survey in Lake Rotorangi is undertaken on a triennial basis. This was completed in the 2023/24 monitoring year. For this survey, a boat travels along the lake edge at consistent speed while staff watch and identify macrophyte species. There have been large changes in the macrophyte community since the surveys began in 1987, where *Lagarosiphon major* was the dominant species, and *Egeria densa* being the next most common. Following on from that, up until 2005, *E. densa* was noted as the most dominant species. In 2005 and 2008, *L. major* was the most dominant species, however, in 2012 it switched back to *E. densa*. Also in 2012, the macrophyte survey first picked up the highly invasive *Ceratophyllum demersum*, also known as hornwort. As predicted in a report prepared by NIWA (Wells 2012), the distribution of hornwort has increased markedly. In 2015, hornwort became more prolific and dominated the middle reaches of Lake Rotorangi, as well as being the only dominant species on the true left bank downstream of the Hāwera water ski club rooms. In 2018, hornwort was the dominant macrophyte in the upper reaches of the lake, however, it should be noted that although the 2018 survey recorded no macrophytes through the mid-section of the lake, it may have been present but obscured by high turbidity. In the previous survey (2021) hornwort was the dominant macrophyte throughout the entirety of the lake, with the exception of a small section at the northern end of the lake that was <2km in length, and in small sections down one arm on the eastern side of the lake, which were instead dominated by *E. densa*.

The current survey results suggest that hornwort has become the dominant species throughout the whole lake. Apart from hornwort, there was only one other macrophyte recorded in this year's survey, *Potamogeton cheesmanii*, a native pondweed. However, *P. cheesmanii* was only found in a small density, approximately 1m^2.

The full survey report is provided in Appendix I.

3.6 Temporal trends

Long-term trend analyses were carried out on eight water quality measures for each monitoring site, as well as the whole lake by combining the two datasets. Long-term trends in trophic level index were also assessed for each monitoring site. Short-term trends were carried out for the same water quality measures, but there were insufficient data to assess trophic level index. These results are summarised by trend direction in Table 13, with the complete results presented in Table 14 and Table 15. An increasing trend direction corresponds to degrading water quality for all of the parameters assessed except Secchi depth. For Secchi depth, an increasing trend corresponds to improving water quality. Further explanation of the trend analysis methodology and interpretation of results is provided in Section 2.4.2.

Table 13 Number of long-term and short-term trends in each trend direction category

	Site	Improving	Degrading	Indeterminate
Long-term (n=26)	LRT000300	3	4	2
	LRT000450	3	4	2
	Whole lake	3	4	1
Short-term (n=24)	LRT000300	4	0	4
	LRT000450	6	0	2
	Whole lake	6	0	2

Long-term trend results were fairly evenly distributed between categories, with three improving trends, four degrading trends and two indeterminate trends observed at each monitoring site (Table 13). Trend directions were consistent between sites for every parameter (Table 14). Improving trends were recorded for DRP, ammoniacal nitrogen, and TN. Degrading trends were observed for TP, chlorophyll *a*, Secchi depth and *E. coli*. There was no clear trend direction observed for nitrite/nitrate at either monitoring site or the combined dataset. The trends with the highest level of confidence were those for chlorophyll *a* (whole lake), TP (LRT000300), DRP (all sites), ammoniacal nitrogen (all sites) and trophic level index (LRT000300 and LRT000450). Except for trophic level index, the rates of annual change associated with this sub-set of trends were all greater than 1%, with the highest rates observed for DRP (improving by 3.05% per year at LRT000450) and ammoniacal nitrogen (improving by 3.54% per year at LRT000450). A lower rate of annual change was observed for trophic level index (0.20% at LRT000300 and 0.24% at LRT000450).

By comparison, the majority of short-term trend results were found to be improving (16 out of 24), with the remainder indeterminate (Table 13). No degrading trends were observed. Improving trends were observed for at least one site for every parameter, except for *E. coli*, for which the trends at both sites and the combined dataset were all indeterminate (Table 15). The trends with the highest level of confidence were those for chlorophyll *a* (LRT000450), TP and DRP (all sites), and ammoniacal nitrogen (LRT000450). For seven out of eight of those trends, the rate of annual change was greater than 5%. The highest rate of annual change was observed for DRP (improving by 10.58%, 8.80% and 13.10% per year at LRT000300, LRT000450 and the combined lake dataset, respectively).

The parameters with evidence of consistent long-term and short-term trend directions include DRP (improving across time periods at all sites), ammonia (improving across time periods at one site), total nitrogen (improving across time periods at one site), and Secchi depth (degrading across time periods at one site). The parameters with evidence of contrasting long-term and short-term trend directions include chlorophyll *a* (degrading to improving at all sites) and TP (degrading to improving at one site). The remaining combinations of sites and parameters showed evidence of a trend over one time period but were indeterminate over the other time period.

Table 14 Long-term trend analysis of selected variables in Lake Rotorangi from the beginning of the monitoring record to 2024

Measure	Site	Seasonal (Yes / No)	No. of data points	Proportion censored	Median Slope	Percent Annual Change	Trend	Confidence (%)
Chlorophyll *a* (photic zone)	LRT00P300	No	111	0.14	0.025	0.89	Likely Increasing	86.49
	LRT00P450	No	111	0.13	0.023	0.95	Likely Increasing	81.43
	Whole Lake	No	222	0.13	0.32	1.23	Very Likely Increasing	92.29
E. coli (surface)	LRT00S300	No	37	0.054	0.18	0.92	Indeterminate	58.18
	LRT00S450	No	38	0.11	0.10	3.40	Likely Increasing	77.99
	Whole Lake	No	75	0.08	0.24	4.89	Likely Increasing	75.06
Total phosphorus (epilimnion)	LRT00E300	No	112	0	0.00030	1.24	Very Likely Increasing	93.36
	LRT00E450	No	112	0	0.000025	0.13	Indeterminate	59.92
	Whole Lake	No	224	0	0.00016	0.77	Likely Increasing	84.15
DRP (epilimnion)	LRT00E300	No	112	0.24	-0.000010	-2.00	Very Likely Decreasing	96.55
	LRT00E450	No	112	0.28	-0.00012	-3.05	Very Likely Decreasing	99.71
	Whole Lake	No	224	0.26	-0.00011	-2.66	Very Likely Decreasing	98.93
Ammonia (epilimnion)	LRT00E300	No	112	0.04	-0.00016	-0.78	Very Likely Decreasing	91.66
	LRT00E450	No	112	0.15	-0.00035	-3.54	Very Likely Decreasing	100
	Whole Lake	No	224	0.098	-0.00029	-1.98	Very Likely Decreasing	99.92
Total nitrogen (epilimnion)	LRT00E300	No	112	0	-0.0045	-0.72	Likely Decreasing	85.69
	LRT00E450	No	112	0	-0.0031	-0.51	Likely Decreasing	82.81
	Whole Lake	No	224	0	-0.0039	-0.63	Likely Decreasing	88.37
Nitrite/nitrate (epilimnion)	LRT00E300	No	108	0.00	0	0	Indeterminate	55.03
	LRT00E450	No	108	0.019	0.0012	0.32	Indeterminate	67.32
	Whole Lake	No	216	0.0093	0.001	0.27	Indeterminate	61.86

Measure	Site	Seasonal (Yes / No)	No. of data points	Proportion censored	Median Slope	Percent Annual Change	Trend	Confidence (%)
Secchi depth	LRT00E300	No	112	0	-0.014	-0.56	Likely Decreasing	77.90
	LRT00E450	No	112	0	-0.014	-0.45	Likely Decreasing	77.09
	Whole Lake	No	224	0	-0.015	-0.52	Likely Decreasing	81.70
Trophic level index	LRT000300	No	30	0	0.0081	0.20	Very Likely Increasing	95.32
	LRT000450	No	30	0	0.0096	0.24	Very Likely Increasing	94.58

Note: Trends of high confidence are identified in red (degrading trend) or blue (improving trend). The monitoring record start date varies depending on the parameter.

Table 15 Short-term (10-year) trend analysis of selected variables in Lake Rotorangi (2014 – 2024)

Measure	Site	Seasonal (Yes / No)	Proportion censored	Median Slope	Percent Annual Change	Trend	Confidence (%)
Chlorophyll *a* (photic zone)	LRT00P300	No	0.093	-0.083	-2.39	Likely Decreasing	71.53
	LRT00P450	No	0.11	-0.22	-7.78	Very Likely Decreasing	90.89
	Whole Lake	No	0.10	-0.18	-6.12	Likely Decreasing	87.23
E. coli (surface)	LRT00S300	No	0.029	-0.38	-1.74	Indeterminate	58.73
	LRT00S450	No	0.11	0.049	1.64	Indeterminate	58.74
	Whole Lake	No	0.072	0.21	3.05	Indeterminate	58.73
Total phosphorus (epilimnion)	LRT00E300	No	0	-0.0011	-4.27	Very Likely Decreasing	94.49
	LRT00E450	No	0	-0.012	-6.35	Very Likely Decreasing	98.87
	Whole Lake	No	0	-0.0013	-5.77	Very Likely Decreasing	99.15
DRP (epilimnion)	LRT00E300	No	0.20	-0.00045	-10.58	Very Likely Decreasing	99.08
	LRT00E450	No	0.25	-0.00026	-8.80	Very Likely Decreasing	98.75
	Whole Lake	No	0.23	-0.00039	-13.10	Very Likely Decreasing	99.08

Measure	Site	Seasonal (Yes / No)	Proportion censored	Median Slope	Percent Annual Change	Trend	Confidence (%)
Ammonia (epilimnion)	LRT00E300	No	0.091	-0.000064	-0.30	Indeterminate	59.19
	LRT00E450	No	0.27	-0.00046	-6.54	Very Likely Decreasing	98.22
	Whole Lake	No	0.18	-0.00031	-2.82	Likely Decreasing	85.40
Total nitrogen (epilimnion)	LRT00E300	No	0	-00020	-0.32	Indeterminate	55.55
	LRT00E450	No	0	0.0086	1.38	Likely Decreasing	70.63
	Whole Lake	No	0	0.0036	0.57	Indeterminate	56.77
Nitrite/nitrate (epilimnion)	LRT00E300	No	0	-0.013	-2.78	Likely Decreasing	81.59
	LRT00E450	No	0.023	0.00063	0.14	Indeterminate	55.55
	Whole Lake	No	0.11	-0.0064	-1.36	Likely Decreasing	72.22
Secchi Depth	LRT00E300	No	0	-0.022	-1.02	Indeterminate	62.75
	LRT00E450	No	0	-0.036	-1.21	Likely Decreasing	77.61
	Whole Lake	No	0	-0.046	-1.70	Likely Decreasing	76.20

Note: Trends of high confidence are identified in red (degrading trend) or blue (improving trend)

4. Discussion

The Council undertook state of the environment monitoring at Lake Rotorangi on four occasions each year during the 2021-2024 period. The results of this monitoring are discussed here.

Over the three-year monitoring period, stratification in Lake Rotorangi varied between sites, seasons and years. Generally, with stratification, the lower layer, the hypolimnion, will be colder with lower dissolved oxygen levels than the top layer, the epilimnion. Anoxic conditions (where DO concentrations are less than 0.5g/m^3) were noted on several occasions. All of the surveys which recorded DO concentrations during February and March found depleted dissolved oxygen near the lakebed. However, due to equipment issues, there were occasions where these measurements could not be taken.

Anoxic conditions in the lower hypolimnion have the potential to result in the release of nutrients from the lakebed sediments. The results from water samples collected from the water column near the lakebed show that the concentrations of ammoniacal nitrogen were elevated relative to the hypolimnion during many of the February and March sampling occasions. Nitrite/nitrate concentrations were elevated in the water column near the lakebed on one occasion, whereas there were no pronounced increases in DRP concentrations observed near the lakebed. It is unclear whether the increase in ammonia results from hypoxic nutrient release or simply occurs due to anoxia causing the reduction of nitrate in the water column to ammonia. A lack of hypoxic nutrient release would indicate that nutrient concentrations in the lakebed sediments remain relatively low (Burns 2006).

Lake water quality during the monitoring period was generally comparable to the long-term record, though there was notable inter-annual variability in the concentrations of some parameters. For total nitrogen, the 2021/22 annual median concentrations were close to, or exceeded the highest annual median concentrations previously recorded for each respective site and sampling depth. Annual median concentrations were comparable to their respective historic medians in 2022/23, and markedly lower than historic medians in 2023/24 (including the lowest annual median concentration on record for the hypolimnion at LRT000450). A similar pattern was observed for nitrate/nitrite concentrations and chlorophyll *a*. For chlorophyll *a*, a new maximum annual median concentration was recorded at LRT000300 in 2021/22, and the second lowest annual median concentrations were recorded at both sites in 2023/24. Total phosphorous and dissolved reactive phosphorous concentrations were not markedly elevated in 2021/22, however a number of phosphorous results in 2023/24 were equal to, or below, the lowest annual median concentrations previously recorded.

This inter-annual variability in key water quality parameters was also reflected in the Trophic Level Index (TLI) scores. In 2021/22, overall TLI scores exceeded, or were close to, the highest previously recorded at both sites. In 2022/23, TLI scores still exceeded the historic median at both sites but were comparable to previous results. In 2023/24, overall TLI scores were the lowest ever recorded at either site. These scores corresponded to the upper end of the eutrophic range in 2021/22, the lower end of the eutrophic range in 2022/23, and near the middle of the mesotrophic range in 2023/24. Historically, the TLI for Lake Rotorangi has tended to sit very close to the mesotrophic-eutrophic threshold.

Based on the assessment criteria set out under NOF in the NPS-FM, the concentrations of water quality parameters recorded during the monitoring period were indicative of varying levels of degradation or disturbance. It should be noted that these assessments do not strictly adhere to the data requirements set out in the NPS-FM (due to sampling frequency), and as such they should be interpreted as indicative gradings.

- Ammoniacal nitrogen concentrations fell within band A, corresponding to minimal toxicity impacts on aquatic life.
- Total nitrogen concentrations achieved band C, corresponding to moderate trophic impacts on aquatic life.

- Total phosphorous concentrations fell within band C at the upper lake site, and band B at the lower lake site. These grades correspond to moderate to low trophic impacts on aquatic life.
- Median chlorophyll *a* concentrations fell within band A at both sites, which indicates that lake ecological communities are healthy and resilient, similar to natural reference conditions. However, maximum concentrations only achieved bands C (moderately impacted) and B (slightly impacted) at the upper and lower lake sites, respectively.
- Lake bottom and mid-hypolimnetic dissolved oxygen concentrations at both sites fell within band D which is below the national bottom line, indicative of significant stress on fish species and the potential for nutrient release from lakebed sediments.
- *E. coli* concentrations achieved band A, corresponding to a low risk of infection arising from swimming and other water sports.

Long-term trend analyses found strong evidence of increasing (degrading) trends in total phosphorous concentrations. However, decreasing trends in dissolved reactive phosphorous concentrations were also observed. This would suggest that increases in total phosphorous may be associated with increasing suspended sediment loads related to soil erosion in the contributing sub-catchments. However, previous attempts to correlate total phosphorous with total suspended sediment have been inconclusive due to the high number of censored values (TRC, 2021). There is evidence of a long-term decreasing trend in Secchi depth, however, this is confounded by an increasing trend chlorophyll *a* concentrations, which will also be contributing to reduced visual clarity.

Long-term trend analyses also found strong evidence of decreasing (improving) trends in ammoniacal nitrogen concentrations, with a rate of annual change corresponding to -1.1% at the upper lake site, and -3.8% at the lower site. Similar decreasing trends have been observed at several long-term river water quality monitoring sites around the region (TRC, 2022). This may be associated with a reduction in point sources discharges over time, with dairy effluent and other wastewater discharges now transitioning to land. However, further analysis is needed to better understand the drivers behind these trends.

Long-term trend analyses of the lake trophic level index data found strong evidence of degrading trends at both lake monitoring sites. However, the rate of annual change is low, with an average increase in TLI of 0.2% per year.

Short-term trend analyses (covering the most ten-year period from 2014-2024) found no evidence of degrading trends across any of the eight water quality parameters assessed. The parameters with evidence of consistent long-term and short-term trend directions include DRP (improving over both time periods at both sites), ammonia (improving over both time periods at one site), total nitrogen (improving over both time periods at one site), and Secchi depth (degrading over both time periods at one site). The parameters with evidence of contrasting long-term and short-term trend directions include chlorophyll *a* (degrading to improving at all sites) and TP (degrading to improving at one site). The remaining combinations of sites and parameters showed evidence of a trend over one time period and were indeterminate over the other time period.

When comparing the April 2024 macrophyte survey results to the previous surveys, it is clear that the invasive Hornwort (*Ceratophyllum demersum*) has continued to spread throughout Lake Rotorangi. *C. demersum* is now the dominant macrophyte, with only one other macrophyte seen during the whole survey being *P. cheesmanii*. However, this was only found in a small density, approximately 1m^2. With this widespread abundance of *C. demersum* in Lake Rotorangi, which is popular for water sports, there is a risk of spread to other lakes where the effects may be severe. Appropriate warning signage regarding the potential problems caused by aquatic weeds and the responsibilities of recreational lake users are in place at the three principal boat ramps in Lake Rotorangi. These were updated in the 2015/16 monitoring year to include specific references to hornwort.

In 2022, RMA Science Ltd. developed the Simplified Contaminant Allocation and Modelling Platform (SCAMP) for Taranaki to estimate catchment contaminant loads and concentrations under a range of management scenarios relating to potential freshwater policy interventions (Cox et al. 2022). The SCAMP model estimates loads and concentrations of total nitrogen and total phosphorous at designated monitoring points, or nodes, in response to theoretical land use scenarios that are applied to the upstream catchment. Updates were carried out in 2024 to incorporate Lake Rotorangi into the model which enables the user to identify the major sources of contaminants entering the lake and estimate the relative loads under a range of theoretical scenarios (Cox 2024).

Total nitrogen and phosphorous loads entering Lake Rotorangi, and their respective sources, are estimated below in Table 16. Of note is the significant proportion of total nitrogen and phosphorus loads attributed to diffuse sources associated with land use. Based on these estimates, diffuse nitrogen losses from land where dairy farming occurs contributes more than 60% of the annual load of total nitrogen entering Lake Rotorangi, while diffuse phosphorus losses from land that is used for sheep and beef farming contributes approximately half of the annual load of total phosphorous.

Table 16 Estimated relative contributions of different sources of total nitrogen and total phosphorous to the overall loads entering Lake Rotorangi

Source	TN	TP
Native forest	1.6%	2.4%
Forestry	1.0%	1.0%
Dairy	62.9%	18.7%
Sheep and Beef	30.5%	50.5%
Urban	0.3%	0.3%
Observable Erosion P	n/a	20.0%
Point Sources	3.6%	7.0%

Note: Observable erosion P refers to the phosphorous that is generated through large scale erosion processes and is included in observed instream loads (see Cox et al. 2022 for further explanation).

Cox (2024) assessed a range of hypothetical management scenarios to determine water quality responses in Lake Rotorangi in order to support the development of the Council's Regional Land and Freshwater Plan (Table 17). Four scenarios were assessed, with the first two corresponding to the continuation of current management options promoted by Council (i.e. the riparian planting programme and redirecting dairy effluent discharges to land). Scenario three included a broad range of established mitigation options, generally accepted as good farm management practices. Scenario four included a range of developing mitigation options that are anticipated for wider uptake by the year 2035.

Table 17 Mitigation scenarios and estimated water quality responses in Lake Rotorangi (from Cox 2024)

Scenario	Lake Rotorangi water quality response (reduction in median concentration)
1. Eliminating all direct discharge of farm dairy effluent (FDE) into waterways (redirecting these discharges to land);	TN: -1% TP: -3% Chl *a*: -2%
2. Completion of the Riparian Management Programme (RMP), in addition to the removal of direct FDE discharges to waterways.	TN: -4% TP: -5% Chl *a*: -5%
3. 'Established' mitigation options (widely accepted good farm management practices), as at 2015 (see Monaghan et al. 2021)	TN: -10% TP: -11% Chl *a*: -11%
4. 'Established' and 'developing' mitigation options (including recently developed novel mitigation practices), anticipated for 2035 (see McDowell et al. 2021)	TN: -32% TP: -21% Chl *a*: -25%

In summary, greater water quality responses were observed progressively through scenarios one to four as the breadth of mitigation options increased. While the Council's riparian programme has been highly effective since commencing 1993, the extensive fencing and planting already established means that there is little room for further improvement (though the current auditing phase is expected to identify where opportunities for enhancing the effectiveness of existing fencing and planting can be achieved). These results highlight the importance of good land management practices to help mitigate impacts on downstream receiving environments.

5. Recommendations

The following recommendations are based on the results of the 2021-2024 water quality and biological monitoring programmes and the contractual requirements of the resource consents held by Manawa Energy Ltd for the Pātea Hydro Electric Power Scheme on Lake Rotorangi. It is recommended:

1. THAT the Lake Rotorangi physicochemical and biological water quality monitoring programme continues 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 Pātea Hydro Electric Power Scheme – aquatic monitoring plan (next scheduled for 2026/27).
2. THAT in the future, the Lake Rotorangi physicochemical and biological water quality monitoring programme continues to be reported on a triennial basis, in the year in which the triennial biological components are undertaken (next scheduled for 2026/27).

Glossary of common terms and abbreviations

anoxia	absence of dissolved oxygen (defined as dissolved oxygen concentrations less than $0.5g/m^3$)
aquatic macrophyte	water plants
benthic	bottom of lake
Secchi disc	measurement of visual clarity (metres) through the water (/vertically)
Chlorophyll *a*	productivity using measurement of phytoplankton pigment (mg/m^3)
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 (surface layer)
g/m^3	grams 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
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)
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	small and microscopic plants and animals living in the water column
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
thermocline	zone of most rapid temperature change in stratified lakes
TLI	trophic level index, a method of measuring the trophic level of a lake
trophic level	amount of nutrient enrichment of a lake
water column	water overlying the lakebed

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Appendix I

Macrophyte survey results

To	Job Manager, Chania Hattle
From	Freshwater Scientist, Amirah Norhayati
Document	3266201
Date	23 April 2024

Macrophyte assessment surveys in Lake Rotorangi are currently undertaken every three years as a requirement of consent 0489-2 (commencing in 2012). Additional surveys have been carried out, dating back to 1987. The previous survey was conducted in April 2021 and the current survey was carried out on 16 April 2024. The survey was undertaken by three Taranaki Regional Council personnel under contract to Manawa Energy. The survey began at 08:30 at the Pātea dam boat ramp and concluded back at the boat ramp at 15:10 (NZST).

The true right of the lake was surveyed on the way to Mangamingi, while the true left of the lake was surveyed on the return to the Pātea dam. The survey was completed in collaboration with the South Taranaki Coastguard skippers and vessel. The boat travelled at approximately 10km/h, which was determined as a speed that allowed personnel to observe macrophytes, while also ensuring the survey was complete before it was too dark to continue. On occasions where there was uncertainty about a macrophyte identification, the boat was turned around to inspect macrophytes further. In addition to this, on occasion, a sample was collected to inspect closer. Larger arms of the lake were entered to identify the macrophytes present, while smaller arms were not entered when they were too shallow for boat access. Despite these arms making up a small proportion of the lake area, they are generally shallower than the main body of the lake and as such provide a disproportionately large habitat for macrophytes. In addition, the arms were more sheltered allowing for less disturbance, which may have influenced the macrophyte community. As macrophytes were passed, the species was called out by observers and this, as well as the location, which was obtained by a "Garmin InReach", was recorded. The dominant macrophyte species within each area were then colour-coded and mapped. Distributions of dominant macrophyte species are shown in Figure 1, with previous data displayed in Figure 2. This survey was carried out on an overcast day with little wind and no rain, which helped increase the ability for observers to see further below the surface of the lake. However, the northern side of the lake had higher turbidity, increasing the difficulty of seeing through the water column, and therefore some macrophyte species may have been disproportionately missed.

Based on Figure 2, there have been large changes in the Lake Rotorangi macrophyte community from when the surveys were first conducted in 1987. In the first survey, in 1987, *Lagarosiphon major* was the dominant species, with *Egeria densa* being the next most common. Following on from that, up until 2005, *E. densa* was noted as the most dominant species. In 2005 and 2008, *L. major* was the most dominant species, however, in 2012 it switched back to *E. densa*. Also in 2012, the macrophyte survey first picked up the highly invasive *Ceratophyllum demersum*, also known as hornwort. As predicted in a report prepared by NIWA (Wells 2012), the distribution of hornwort has increased markedly. In 2015, hornwort became more prolific and dominated the middle reaches of Lake Rotorangi, as well as being the only dominant species on the true left bank downstream of the Hāwera water ski club rooms. In 2018, hornwort was the dominant macrophyte in the upper reaches of the lake, however, it should be noted that although the 2018 survey recorded no macrophytes through the mid-section of the lake, it may have been present but obscured by high turbidity. In the previous survey (2021) hornwort was the dominant macrophyte throughout the entirety of the lake, with the exception of a small section at the northern end of the lake that was <2km in length, and in small sections down one arm on the east side of the lake, which were instead dominated by *E. densa*.

The current survey suggests that hornwort has taken over and has become the dominant species throughout the whole lake. Apart from hornwort, there was only one other macrophyte recorded in this year's survey, *Potamogeton cheesmanii*, a native pondweed (Table 1). However, *P. cheesmanii* was only found in a small density, approximately $1m^2$.

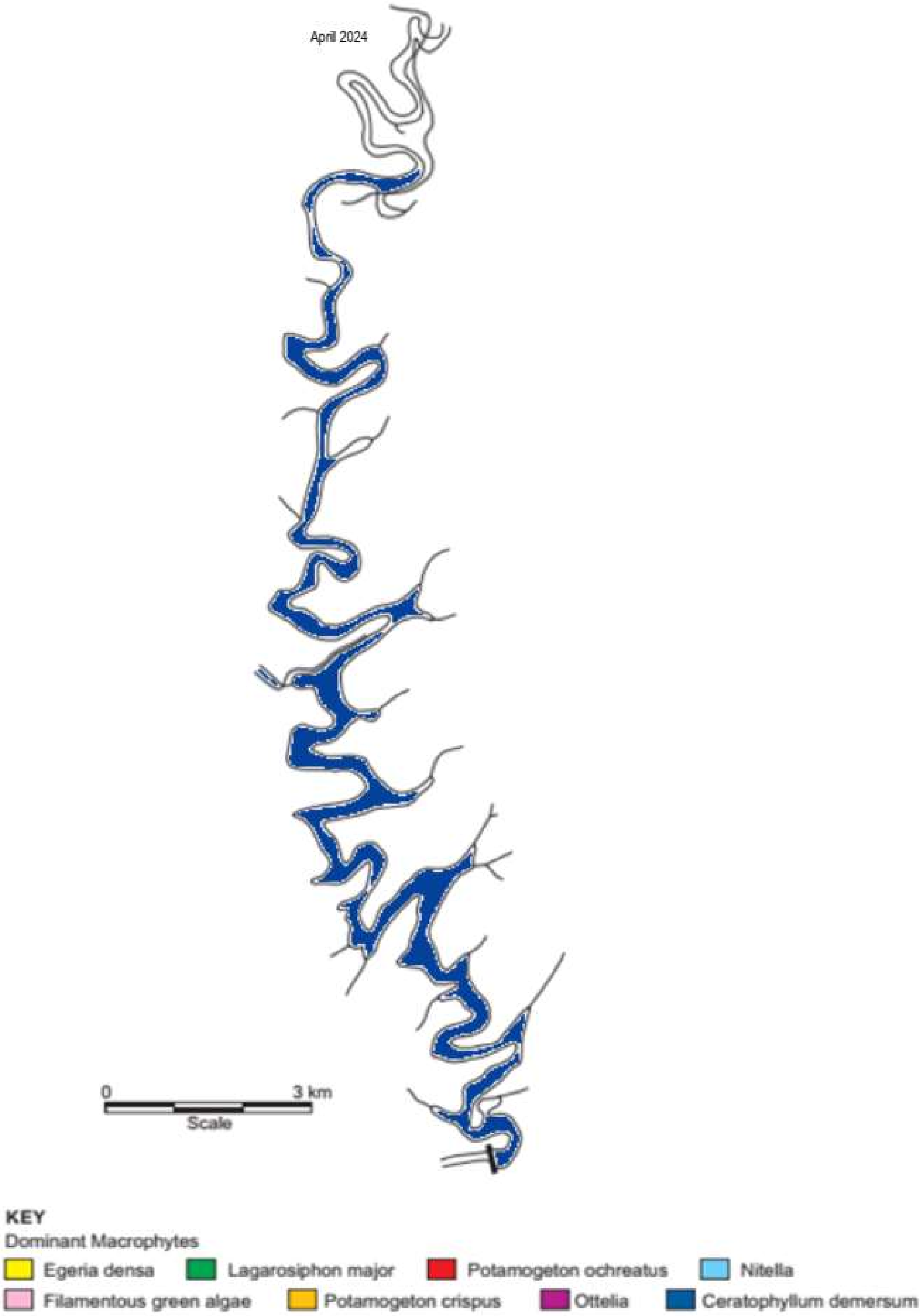


Figure 1 Dominant macrophytes recorded in Lake Rotorangi on 16 April 2024

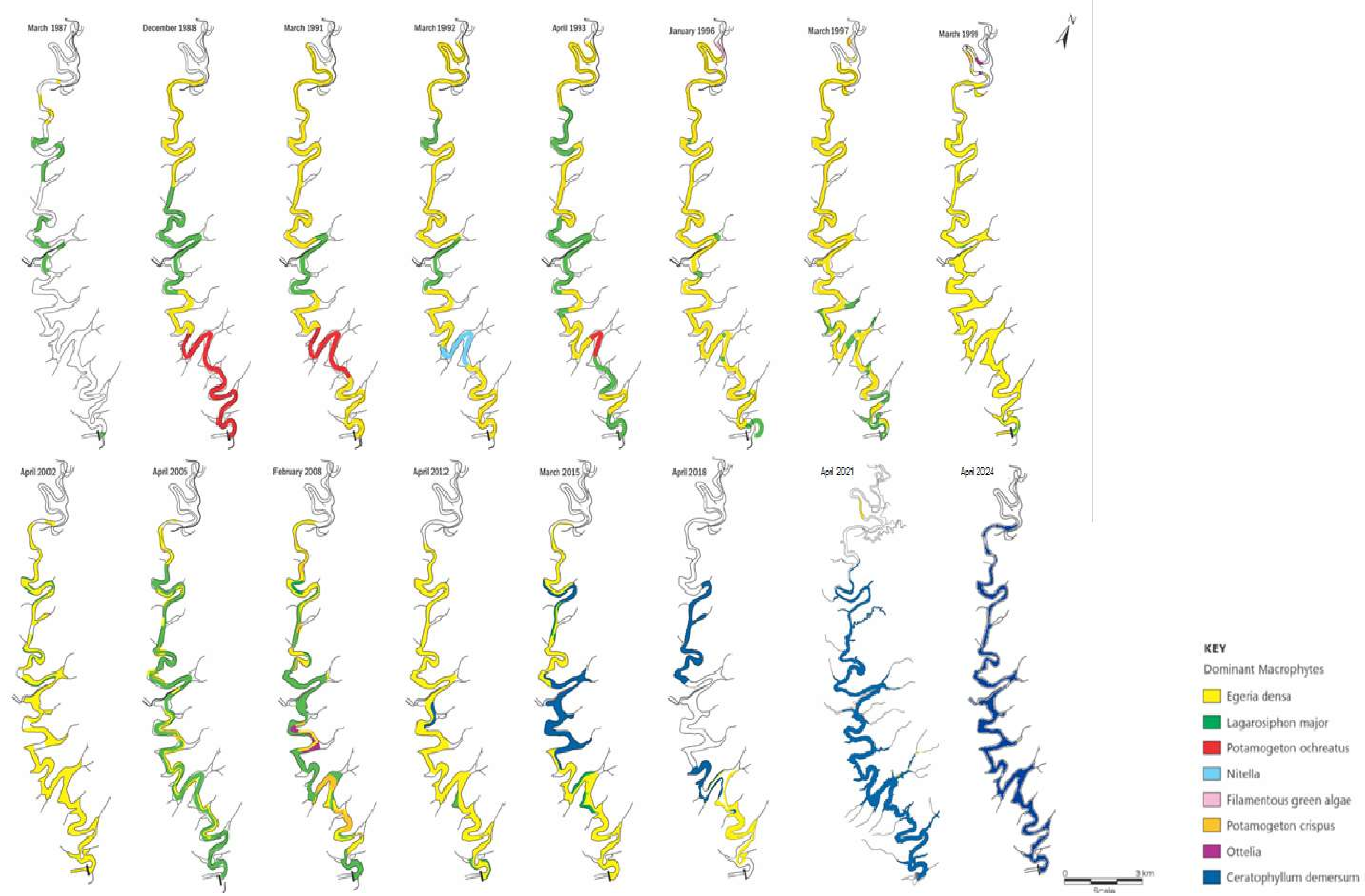


Figure 2 Dominant macrophytes recorded in Lake Rotorangi from 1987 to 2024

Actual coverage of macrophytes throughout the lake remains restricted to the edges of the lake and extends further into the middle of the lake only on the inside of large wide bends where shallow areas permit the spread of these macrophytes. In areas where the banks drop away quickly, the macrophytes have been previously recorded in patches rather than large continuous thick growths. However, the presence of *C. demersum* is causing this to change, as this species can grow taller and in deeper water than *E. densa* and L. major, enabling it to colonise more of the lakebed. NIWA state that *C. demersum* can grow >10m in depth, and there have been reports from Wells et al. of *C. demersum* growing up to 14.5m, and, based on the DOC website (2022), *C. demersum* has been observed growing in water as deep as 16m. Despite this, in the areas with the steepest banks, there are still patches of lakebed clear of macrophytes.

A summary of the aquatic macrophyte species found in Lake Rotorangi in the summer-autumn surveys performed between 1986 and 2021 is presented in Table 1.

Table 1 Aquatic macrophytes recorded in Lake Rotorangi between 1986 and 2024.

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	Apr 21	Apr 24
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 have been recorded in Lake Rotorangi over the 38-year record. The introduced *E. densa* and *L. major* have been the most commonly observed macrophytes, both of which were not observed in the current survey. Another species frequently recorded is *Potamogeton crispus*, with this species even dominating parts of the lake in 2008. However, in the 2015 survey, this species was recorded only at the head of the lake, and not in abundance. It has not been recorded in the most recent two surveys. *Potamogeton ochreatus* was recorded in the previous survey, although this was only noted in one small patch and was not dominant in any part of the lake. Similarly, *Potamogeton cheesmanii,* was recorded in the current survey, but only in a small patch, and it was not dominant. However, it is important to note that just because no other macrophyte species were identified, it does not mean they were not present.

Some species may be present in small densities that are easy to miss, or some species may not reach as high in the water column making them more difficult to observe. However, personnel took precautions to ensure accuracy by travelling at slow speeds and sampling on a day with suitable weather conditions i.e.

with no rain and little wind, to ensure the water surface remained unbroken and reasonably flat, which increased clarity. There were also three observers on the boat to maximise the certainty of noticing any other macrophyte species. In addition, personnel stopped at small inlets to observe macrophyte species. Large amounts of debris, including fragmented macrophytes, logs, and rubbish were observed in these small inlets (as seen in Figure 3). These fragments allowed us to see what other species may be present in the lake. However, the only macrophyte observed in these inlets was hornwort.

Figure 3 Small inlet where debris washes in, and extra stops were made to investigate the macrophyte species

While on the survey, marginal edge wet-adapted species were also observed, these included:

- *Persicaria* Spp. (exotic)
- *Juncus* Spp. (exotic)
- *Carex* Spp. (all species were natives)
- *Juncus articulates* (exotic)
- *Callitriche* Sp. (likely the invasive species Callitriche brutia var. hamulata) (exotic)
- *Salix fragilis* × *S. euxina* Crack willow (exotic)
- *Cyperus ustulatus*
- *Isolepis prolifera*
- *Hesperantha coccinea* Scarlet river lily (exotic)
- *Typha orientalis* Raupō

The Department of Conversation (DOC) collected environmental DNA (eDNA) samples from Lake Rotorangi on 8 February 2023. This picked up a strong signal of hornwort at all six sample locations. There were also other aquatic plants detected including *E. densa*, which had a weak signal in one sample. *Glossostigma elatinoides*, a small mud mat that is popular in the aquarium trade, but native to New Zealand was also detected in a weak signal at one location. *Lotus* was also detected in a weak signal but at two locations. To reduce eDNA sample contamination, DOC personnel used a 10% bleach solution on gear, as per the Wilderlab guidelines. It is important to note, that there may be contamination of DNA through vessels entering Lake Rotorangi from other waterways, as they do not go through the same thorough decontamination process carried by DOC. Conversely, although eDNA is a great tool for assessing the presence of species, it is unlikely it will pick up every species in a water way.

In the current survey, two fish species, rudd (*Scardinius erythrophthalmus*) and *Perca fluviatus* (Perch) were also seen. Approximately 50 rudd and 20 perch were seen, which would have been a very small proportion of the actual lake population. The distribution of *Potamogeton* spp. may be influenced by the large rudd population in the lake. A 2002 study by Lake et al. found that rudd preferred grazing on *P. ochreatus* over *E. densa* and *L. major*, while *C. demersum* was least preferred. Although *P. crispus* was not included in this study, its similarities to *P. ochreatus* indicate that it also would be preferentially consumed by rudd, explaining the reduced abundance of *Potamogeton* spp. in Lake Rotorangi in recent years.

A survey undertaken by NIWA in 2012 recorded four macrophyte species that had not previously been recorded in Lake Rotorangi. It is unlikely that these species were new additions to the lake. Rather, these species were either not widespread or had growth habits that caused them to be relatively discreet e.g. low-growing plants that inhabit deep water. These species were only recorded when the boat was stationary (*G. elatinoides*) or by divers (*C. australis, L. ruthiana and N. cristata*). It is unlikely that these species will ever become abundant.

C. demersum is considered highly invasive, and as predicted by NIWA (Wells, 2012) has become dominant in the lake. Extensive weed beds like the ones seen in the current survey can result in deoxygenated water, which can then cause nutrient release from the lake bottom. However, Lake Rotorangi has steep littoral gradients, meaning that this deoxygenating process is less likely to occur. However, this deoxygenation of the lake bottom and nutrient release is a possibility for surrounding lakes that have a high risk of hornwort being spread to. In addition, Wells (2012) stated that hornwort may displace native submerged vegetation, which is evident through the current survey results.

Already in 2012, Wells stated that hornwort was too widespread in Lake Rotorangi to the point where containment and eradication were no longer possible. However, they did state that grass carp could be a viable option if they were contained above the dam. But otherwise, the herbicide diquat would be the best option for aquatic weed control. However, Wells (2012) states that spray results should be monitored one month after treatments so the efficacy of the treatment is recorded. Another recommendation was that there should be control around the boat ramps to reduce the spread to surrounding water bodies.

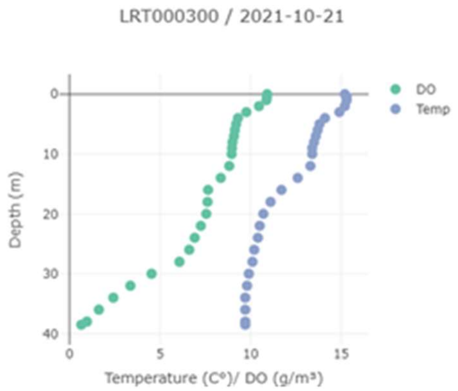
With the increased prevalence of hornwort at Lake Rotorangi comes a greater potential for spread to nearby lakes where impacts could be much more severe. In 2021, hornwort was recorded in Lake Herengawe, south of Lake Rotorangi, for the first time. Considering the proximity of Lake Rotokare to the Glen Nui boat ramp, it may be worthwhile controlling *C. demersum* in the vicinity of the Glen Nui boat ramp to help prevent its spread. The usefulness of this may be subject to further investigation. In addition, the use of better signs may encourage recreational water users to take steps to prevent the transfer of hornwort. Wells (2012) also says that hornwort near boat ramps will increase the ability of it to spread to other lakes.

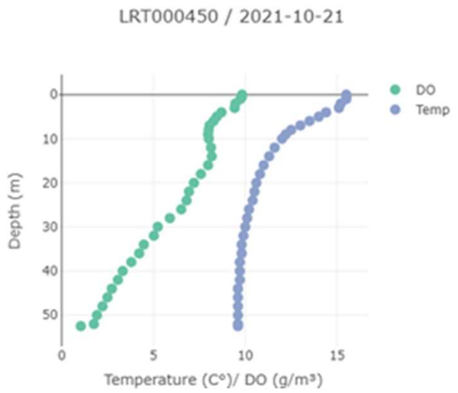
Overall, it is clear that hornwort has increased dramatically since 2012 and is now the dominant macrophyte in Lake Rotorangi. Hornwort negatively impacts the hydroelectric power scheme and can spread to surrounding lakes and dominate the macrophyte communities resulting in negative ecological implications. Although eradicating hornwort in Lake Rotorangi is no longer feasible, steps should be taken to mitigate the spread to surrounding water bodies.

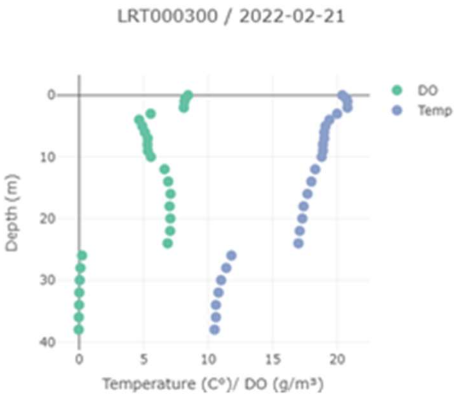
Appendix II

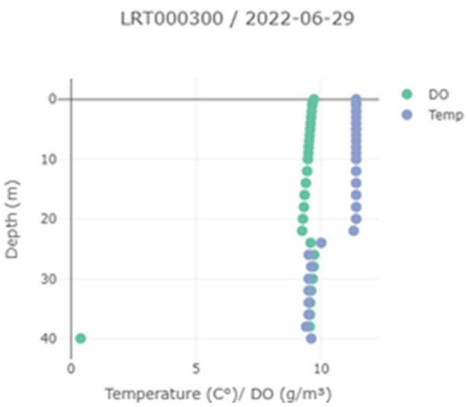
Depth profiles

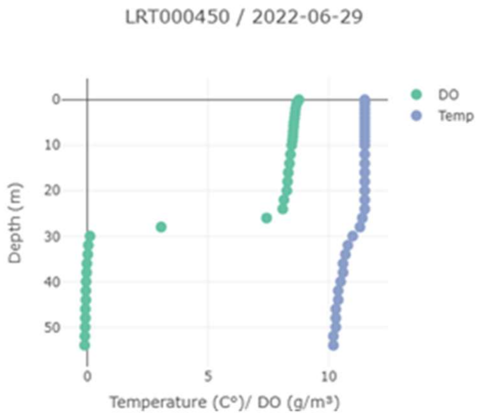
Depth profiles of dissolved oxygen and temperature (2021/22)



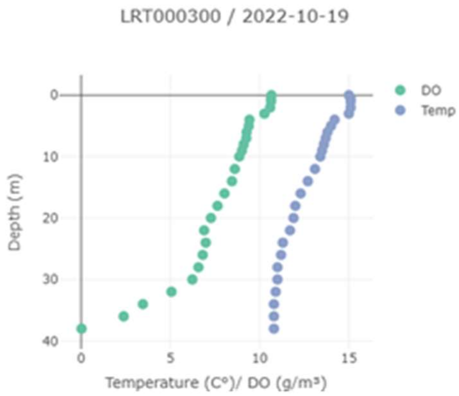


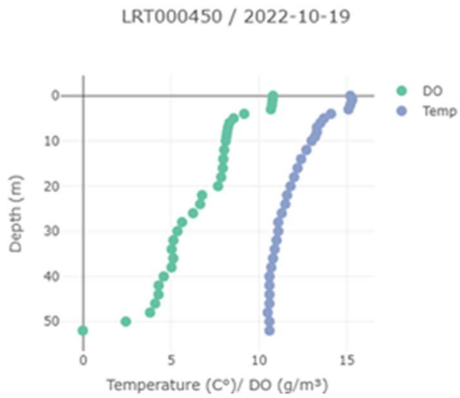


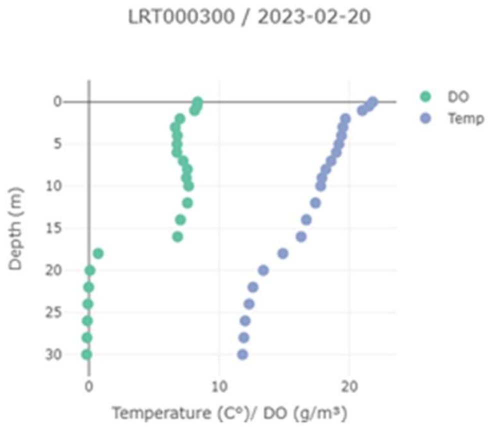


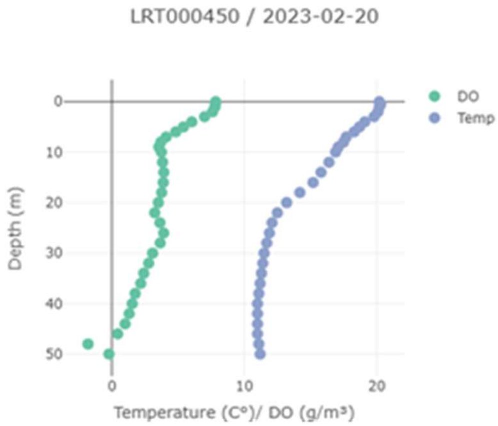


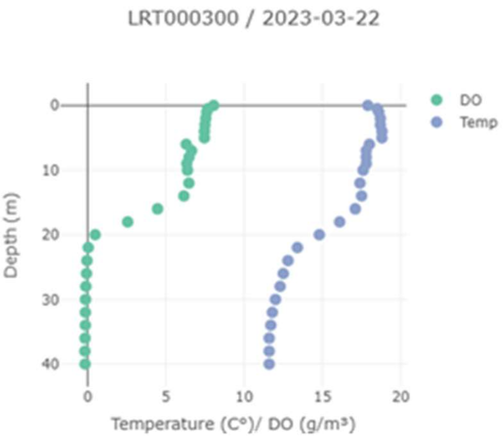
Depth profiles of dissolved oxygen and temperature (2022/23)

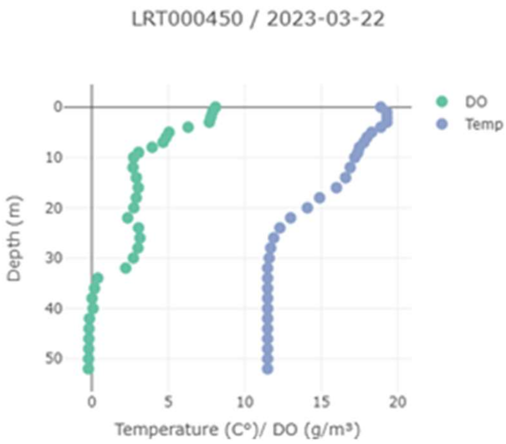


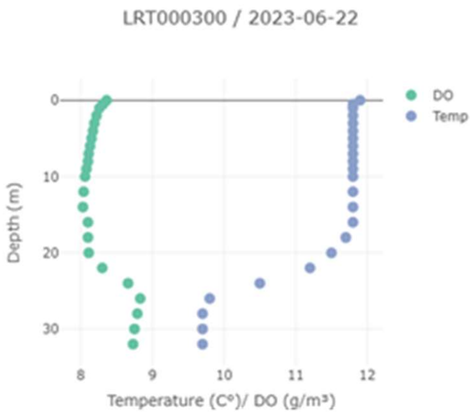




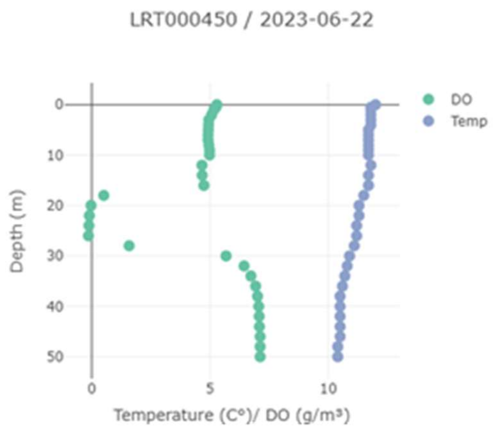






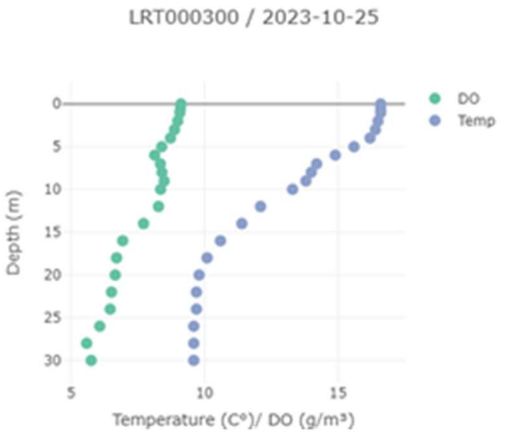


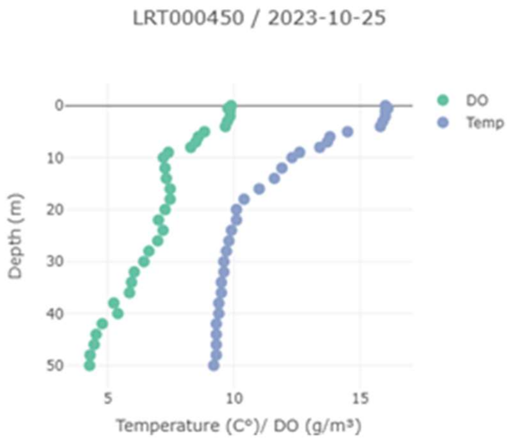
LRT000300 / 2023-06-22
DO
Temp
Depth (m)
Temperature (C°)/ DO (g/m³)

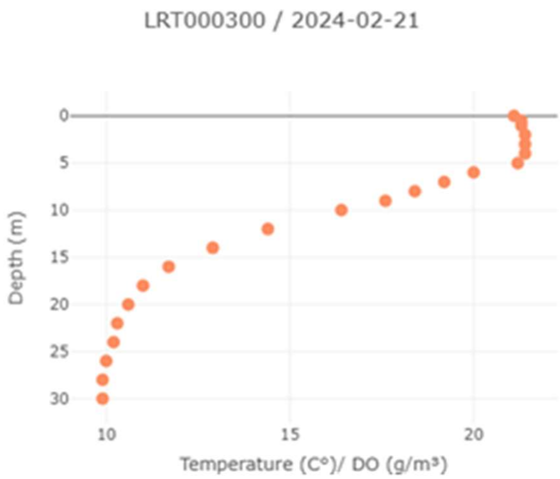


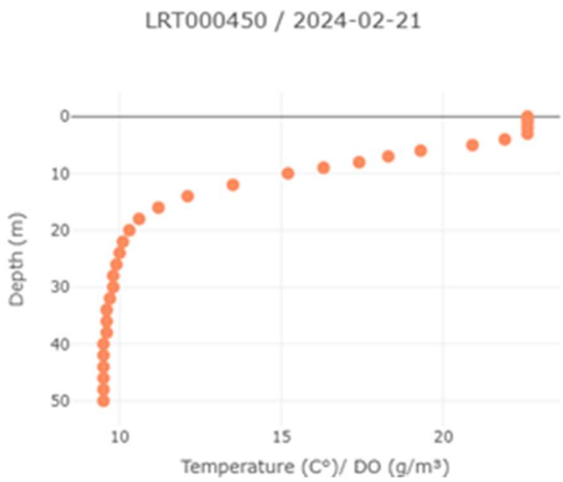
LRT000450 / 2023-06-22
DO
Temp
Depth (m)
Temperature (C°)/ DO (g/m³)

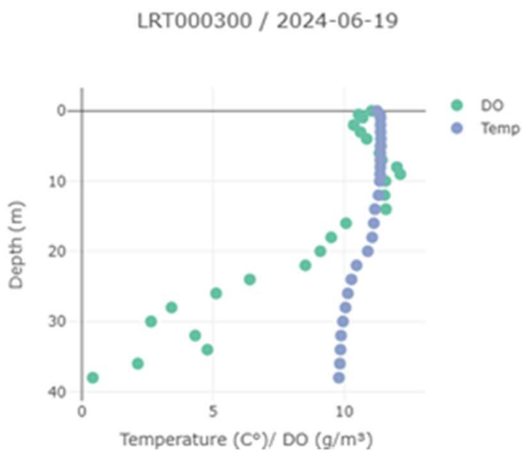
Depth profiles of dissolved oxygen and temperature (2023/24)

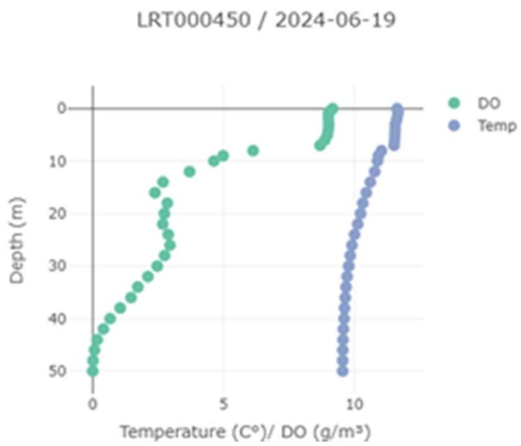












Appendix III

Summary of current water quality results and long-term statistics

Parameter	Site	Sampling depth	Previous annual median minima	Previous annual median maxima	Long-term annual median	2021/22 annual median	2022/23 annual median	2023/24 annual median
Total nitrogen (g/m^3)	LRT000300	Epilimnion	0.30	0.99	0.61	0.93	0.66	0.48
		Hypolimnion	0.65	0.97	0.77	**0.98**	0.77	**0.65**
	LRT000450	Epilimnion	0.45	0.84	0.56	**0.88**	0.63	**0.41**
		Hypolimnion	0.40	0.88	0.73	0.84	0.81	0.64
Nitrite/ nitrate (g/m^3)	LRT000300	Epilimnion	0.16	0.69	0.33	0.57	0.40	0.20
		Hypolimnion	0.07	0.79	0.53	0.70	0.48	0.51
	LRT000450	Epilimnion	0.17	0.58	0.329	**0.58**	0.41	0.23
		Hypolimnion	0.21	0.77	0.61	0.71	0.66	0.51
Ammoniacal nitrogen (g/m^3)	LRT000300	Epilimnion	0.0068	0.027	0.014	0.014	**0.0053**	0.014
		Hypolimnion	0.0022	0.110	0.029	0.018	0.022	0.0032
	LRT000450	Epilimnion	0.001	0.028	0.0083	0.0059	0.0024	0.0033
		Hypolimnion	0.0003	0.015	0.0017	0.0006	0.0011	0.00065
Total phosphorous (g/m^3)	LRT000300	Epilimnion	0.012	0.068	0.022	0.028	0.027	0.019
		Hypolimnion	0.014	0.11	0.022	0.023	0.031	**0.011**
	LRT000450	Epilimnion	0.010	0.050	0.018	0.025	0.020	**0.010**
		Hypolimnion	0.010	0.076	0.017	0.017	0.019	**0.008**
Dissolved reactive phosphorous (g/m^3)	LRT000300	Epilimnion	0.0002	0.009	0.0051	0.0043	0.0018	0.0018
		Hypolimnion	0.0033	0.013	0.0073	0.0041	0.0059	**0.0026**
	LRT000450	Epilimnion	0.0002	0.011	0.0037	0.0042	0.0017	**0.0002**
		Hypolimnion	0.0006	0.012	0.0059	0.0058	0.0054	0.003
Secchi depth (m)	LRT000300	Surface	0.72	3.9	2.54	1.46	1.15	2.48
	LRT000450	Surface	0.43	4.42	3.2	1.40	1.73	3.35
Chlorophyll a (mg/m^3)	LRT000300	Photic zone	1.25	5.05	2.48	**5.57**	3.60	**1.05**
	LRT000450	Photic zone	1.25	8.70	2.23	2.09	2.40	1.35
E. coli (per 100mL)	LRT000300	Surface	<1	184	21	26	13	18
	LRT000450	Surface	1	6	4	5	**9**	2
TLI	LRT000300	n/a	3.98	4.93	4.17	**4.94**	4.48	**3.80**
	LRT000450	n/a	3.73	4.97	3.98	4.62	4.20	**3.40**

Note: Colours denote annual median results in the current monitoring period that exceeded, or were equal to the lowest (blue) or highest (orange) annual medians previously recorded. TLI is calculated as an annual average score, not an annual median.