Lake Rotorangi

State of the Environment Monitoring

Annual Report

2019-2020

Technical Report 2021-09

Working with people | caring for Taranaki

Taranaki Regional Council

Taranaki Regional Council
Private Bag 713
Stratford

ISSN: 1178-1467 (Online)
Document: 2540341 (Word)
Document: 2795799 (Pdf)
November 2021

Lake Rotorangi

State of the Environment Monitoring

Annual Report

2019-2020

Technical Report 2021-09

Taranaki Regional Council
Private Bag 713
Stratford

ISSN: 1178-1467 (Online)
Document: 2540341 (Word)
Document: 2795799 (Pdf)
November 2021

Executive summary

Lake Rotorangi was formed in May 1984 by the construction of an earth fill dam on the Patea 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 results of monitoring for the period July 2019-June 2020.

Four water quality surveys were undertaken at two sites during the period under review. One site is located in the mid reaches of the lake, while the second site is located nearer the dam.

Thermal stratification changes during the year were typical of those which have been recorded in previous surveys. Thermal stratification was beginning to form in the spring survey, was fully developed in the later summer and early autumn surveys, but had overturned by the winter survey. Oxygen depletion was evident in the late summer and early autumn surveys, and remained at the lower lake site in the winter survey despite the uniform water temperatures throughout the water column. This pattern has been typical of Lake Rotorangi since monitoring began.

Physicochemical monitoring showed that lake water chemistry largely remained within the range which has been typical of the lake over the past 25 years. *E. coli* levels were within the 'surveillance' level under contact recreational guidelines for the entire period in the lower lake (site L3), and in the mid lake (site L2) in late summer and early autumn, while in spring and winter the 'action' level was reached at this site.

The trend analysis methodology implemented for this report has been updated from that used in previous years. This has resulted in changes to the results when compared to those previously reported. The methodology is briefly described in Section 2.4, with more detail provided in appendix I. The changes made, and their implications are discussed in section 4.1 and Appendix VII Summary tables comparing the old and new interpretations and methodologies are provided in Appendices VI and VII.

Increasing trends in chlorophyll-a, conductivity and total phosphorus were detected, while total nitrogen showed a decreasing trend for the period 1996-2020. When analysed over the most recent ten year period, decreasing trends in total phosphorus and chlorophyll-a, and an increasing trend in conductivity were detected.

National Objectives Framework (NOF) attributes for total nitrogen and phytoplankton classify the lake in the 'B' band, or as being slightly impacted compared to reference conditions, while total phosphorus concentrations classify the lake as being in the 'C' band, or moderately impacted compared to reference conditions.

The trophic state of the lake remains eutrophic, while on the basis of individual sites L2 is eutrophic and site L3 is mesotrophic. This is despite the period used for the calculation being updated from the calendar year to the year beginning in June. This change allows an entire period of stratification to be captured in a single year and aligns with recommendations for use of the TLI (Burns *et al.* 2000; Schallenberg & van der Zon 2021).The updated trend methodology suggests TLI for the lake as a whole is being maintained; whereas previously a highly significant deterioration of minor magnitude was reported (0.01±0.01 TLI units per year).

The monitoring of Lake Rotorangi will continue in its present format for the 2020-2021 monitoring year, with the inclusion of the triennial biological surveys for consent compliance purposes. This report also includes recommendations for the 2020-2021 monitoring year.

Table of contents

List of tables

List of figures

1 Introduction

1.1 General

The *Resource Management Act 1991* (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) has 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 (1994)*.

The SEM programme is made up of a number of individual monitoring activities, many of which are undertaken and managed on an annual basis (from 1 July to 30 June). For these annual monitoring activities, summary reports are produced following the end of each monitoring year (i.e., after 30 June). Where possible, individual consent monitoring programmes have been integrated within the SEM programme to save duplication of effort and minimise costs. The purpose of annual SEM reports is to summarise regional environmental monitoring activity results for the year, and provide an interpretation of these results, together with an update of trends in the data.

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 improving environmental quality in Taranaki over the past two decades. The second report (for the period 1995-2000) was published in 2003 (TRC, 2003a). Data spanning the ten year period 1995 to 2005 was used in the preparation of a trend report (TRC, 2006a). The third State of the Environment report (for the period 1995 to 2007) was published (TRC, 2009a) and included trend reporting and the fourth report (for the 1995 to 2014 period) has been published (TRC, 2015a). The provision of appropriate computer software statistical procedures allows regular reporting on trends in the environmental quality over time, in relation to Council's ongoing monitoring activities, now that there has been an accumulation of a comprehensive dataset of sufficient duration to permit a meaningful analysis of trends (i.e. minimum of 10 years).

1.2 Lake Rotorangi

Lake Rotorangi was formed in May 1984 by the construction of an earth fill dam on the Patea River for the purpose of 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.

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.

The Patea catchment upstream of the dam covers an area of 86,944 ha. This includes both the Patea river sub-catchment and the Mangaehu River sub-catchment. Approximately 1% of this area is urban, while another 8% is conservation land. The remainder of the catchment is in pastoral land, with a mixture of dry stock and dairy farming in the catchment. Council Hill Country plans addressing land management and sediment issues cover 50% of the catchment, primarily in the area where dry stock faming is the dominant land use.

The trophic level of Lake Rotorangi has been increasing at a very slow rate since monitoring began (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).

1.2.1 Lake stratification processes

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 caused by changes in the density of water at differing temperatures. This results in the surface water body (epilimnion) being separated 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. Overturn is the process whereby cooling of the epilimnion water breaks down the physical separation of the epilimnion and hypolimnion, allowing the discrete layers to mix together.

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 decreases 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.

Furthermore, as oxygen depletion occurs in the hypolimnion, this 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

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 conditions with regard to stratification 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 Tangahoe Valley Road)	E1729856 N5626435
LRT000450	L3 (near Patea Dam)	E1734948 N5621974

The targeted conditions are described in Table 2. Sampling in the specified months is aimed to be undertaken on or near the 20^{th} of the month. The dates sampled in the 2019-2020 year are also provided in Table 2.

Table 2 Seasonal sampling and targeted stratification conditions

Season	Month	Target conditions	Sampling date
Spring	October	Pre-stratification	17 October 2019
Late Summer	February	Stable stratification	19 February 2020
Early Autumn	March	Pre-overturn	19 March 2020
Winter	June	Post-overturn	23 June 2020

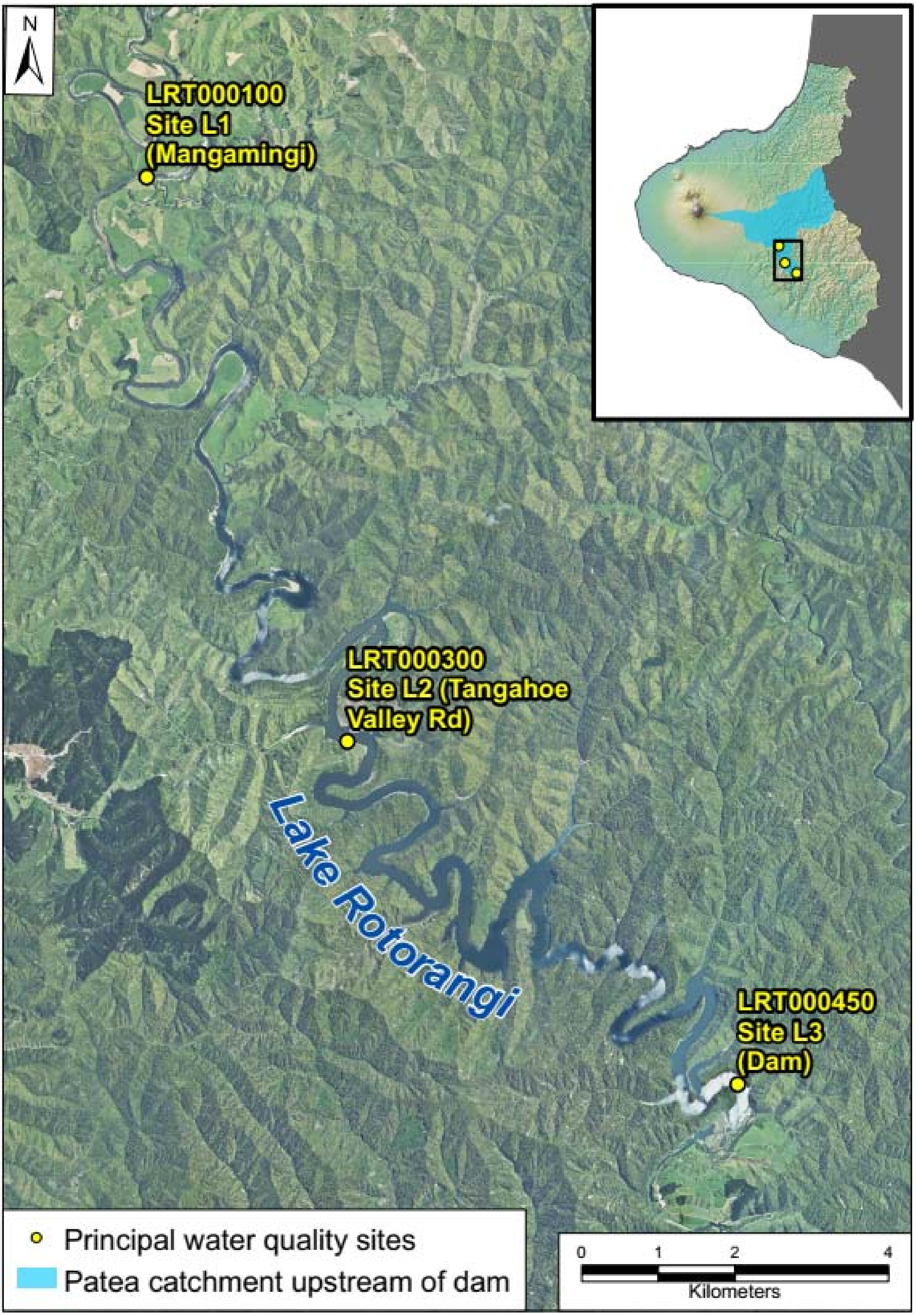


Figure 1 Location of monitoring sites in Lake Rotorangi with inset showing the location and catchment of the lake. Sites L2 and L3 are currently monitored, while monitoring at Site L1 was discontinued in 2010 due to the predominantly riverine nature of the lake at this northern location

2.1 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 represent conditions in the epilimnion and the hypolimnion. In February and March (under 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	Surface	Epilimnion	Hypolimnion	Lower hypolimnion[1]
Black disc transparency	x			
Secchi disc transparency	x			
pH	x	x	x	x
Conductivity	x	x	x	
Turbidity	x	x	x	x
Suspended solids	x	x	x	
E. coli	x			
Dissolved reactive phosphorus		x	x	x
Total phosphorus		x	x	x
Ammoniacal nitrogen		x	x	x
Nitrite nitrogen		x	x	
Nitrate nitrogen		x	x	
Nitrate and nitrite nitrogen		x	x	x
Total Kjeldahl nitrogen		x	x	
Total nitrogen		x	x	

[1] Sampled in late summer and early autumn only

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

2.2 Biological monitoring

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

Triennially, a benthic macroinvertebrate sample is collected at each site in conjunction with the spring physicochemical monitoring. A macrophyte survey is also undertaken triennially in autumn. Both the benthic macroinvertebrate and the macrophyte survey are next due in the 2020-2021 monitoring year.

2.3 Trophic state

The trophic level index (TLI) is calculated for the lake as a whole as well as for individual sites. The equations used vary from those used by Burns (1999), and are consistent with those used by Lakewatch (which was previously used to calculate the TLI). This change to the equation for secchi disc was made after removal of peat-stained lakes, and is appropriate for Lake Rotorangi which is not affected by peat.

Furthermore, following the Lakewatch methodology, the calculation of TLI is dependent on the stratification of the lake. Epilimnetic data is used during stratified periods, while both epilimnetic and hypolimnetic data is used when the lake is isothermal (defined as less than 3°C differences between the surface and lake bottom water temperature). Censored values have been treated as the detection limit in the calculation of the annual average values of the four parameters used. The annual average values are then input into equations to calculate the four components of the TLI as follows:

$$TLc = 2.22 + 2.54 \log (Chla)$$
$$TLs = 5.56 + 2.60 \log ((1/Secchi) - (1/40))$$
$$TLp = 0.218 + 2.92 \log (TP)$$
$$TLn = -3.61 + 3.01 \log (TN)$$

These four component values are then averaged to obtain the overall TLI.

It should be noted that in previous reports the TLI has been calculated per calendar year. In this report an adjustment has been made to this calculation, so that the analysis year is from July-June to align with the reporting period. Furthermore, this change aligns with the recommendation in Burns et al, (2000) and Schallenberg & van der Zon (2021) by ensuring that the calculation year includes an entire period of stratification. Although Burns et al, (2000) and Schallenberg & van der Zon (2021) recommend using a September to August calculation period to best align with the stratification cycle, in this instance the standardised sampling regime used in Lake Rotorangi does not include sampling between July-October. Because of this the calculation on the existing dataset will provide the same result whether the annual period starts in July or September.

2.4 Analysis

A number of changes to data analysis methodologies have been implemented in this report. A brief description of the current methods used is given below, with a more detailed discussion in Appendix I. A discussion of how these differ from methods used in previous TRC SEM lake reports is given in Section 4.1 and Appendix VII of this report.

In this report, trend analysis has been carried out using the LWP-Trends library R package (version 1901), developed by Land Water People (LWP) 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 previous TRC Lake SEM reports, 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).

The data is assessed using a Kruskal-Wallis test to determine whether the data is seasonal. Either a Mann-Kendall or seasonal Kendall test is used to determine the trend direction. A trend rate and confidence in the trend are also generated using a sen-slope regression. Censored data is handled using the methods of Helsel (2011). A note is included when this is affected by censored data, which generally indicates that the trend rate is smaller than can be detected. The confidence in the trend direction is assessed following the credible interval assessment method of McBride (2019). The confidence in the reported trend direction (ranging from 50% to 100%) is categorised based on the categories in Table 4.

Table 4 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%

The trend methods implemented are limited to identifying a single direction (monotonic) trend over time. In many cases, trend in environmental data may vary throughout the time series, due to changes in conditions or individual events resulting in changed trends. A Loess curve has been overlaid on the trend analysis to assist with assessment of non-monotonic trends and investigation into causes of any changes in trends. In addition, a comparison of long term (25 year) and short term (10 year) quantitative trends is undertaken.

In the case of parameters which 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 during the stratified period mean that combining the data from both stratified layers may mask any trends present. For the analysis of the lake as a whole, results taken at different sites, within the same layer of the water column and on the same day, are averaged to provide a single result. These average values are analysed as described above. Both the use of epilimnion data and averaging across the whole lake are consistent with national reporting (Larned et al, 2015).

3 Results

3.1 General observations/hydrological conditions

Sampling was undertaken on the dates specified in Table 2. General observations made on each of the sampling occasions during the period under review are presented in Table 5.

Table 5 Observations at Lake Rotorangi monitoring sites on sampling occasions during 2019-2020

Date	Lake level (m asl)	Weather	Wind		Lake appearance	
			L2	L3	L2	L3
17 October 2019	75.7	Broken cloud, fine	Light NW	Moderate NW	Turbid, brown; surface rippled	Slightly turbid, dark green; surface rippled
19 February 2020	77.3	Overcast, drizzle; heavy rain preceding	Calm	Calm	Clear, dark green; surface flat	Clear, dark green; surface rippled
19 March 2020	76.8	Overcast, light rain	Light NW breeze	Calm	Clear, green-brown; surface rippled	Clear, brown-green; surface flat
23 June 2020	77.0	Foggy	Calm	Calm	Slightly turbid, brown; surface flat	Clear, brown-green; surface flat

The synthetic inflow data for Lake Rotorangi is presented in Figure 2. 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.

The spring survey occurred under fresh recession inflow conditions following three moderate freshes in the preceding month. The late summer and early autumn surveys were carried out under steady baseflow conditions, with one minor fresh in the month preceding the late summer survey, and two moderate and two minor freshes in the month preceding the early autumn survey. The winter survey was performed under fresh recession inflow conditions, with three moderate and one minor fresh in the preceding month.

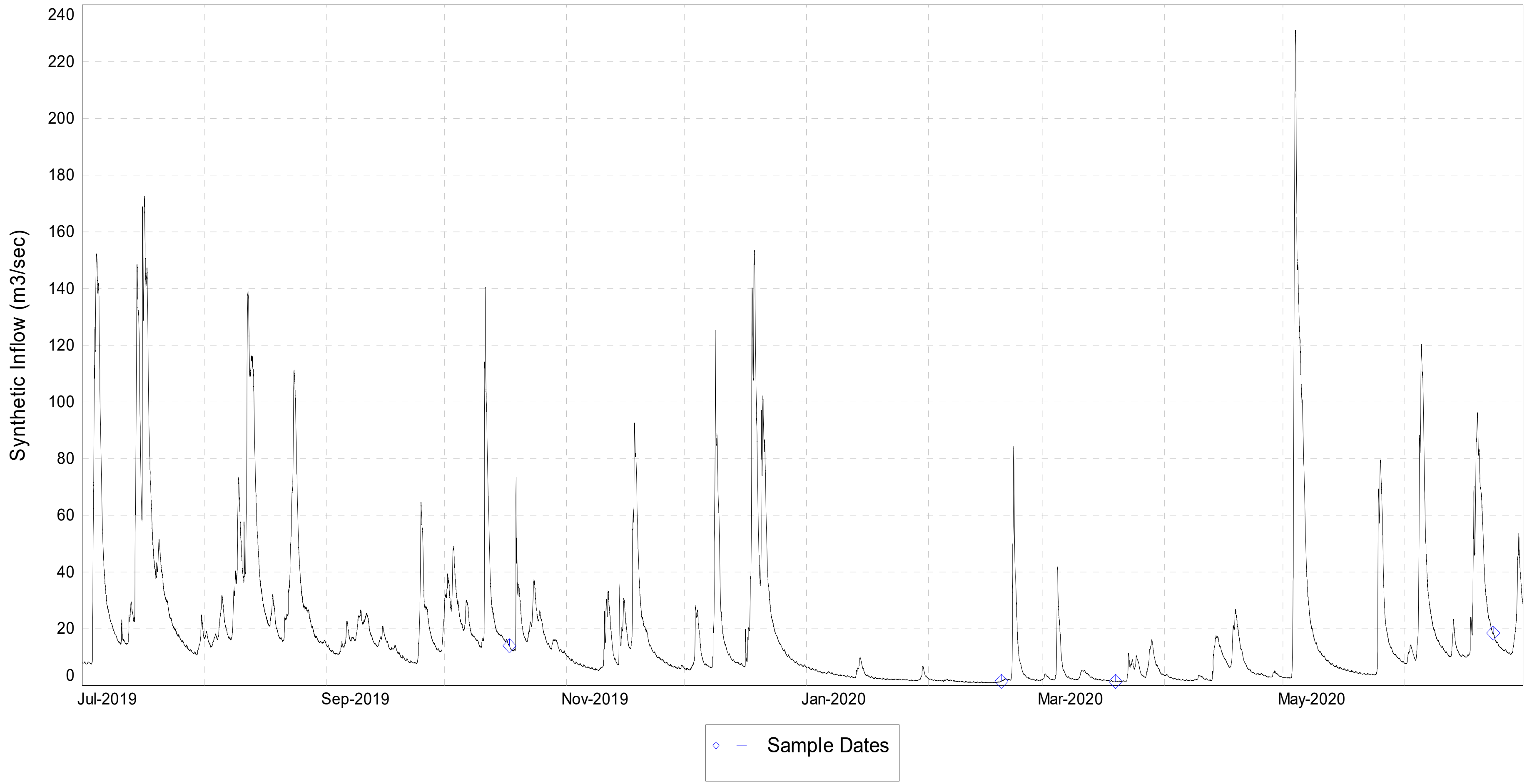


Figure 2 Synthetic inflow at Lake Rotorangi for the period 1 July 2019 to 30 June 2020

3.2 Physicochemical

Physicochemical monitoring data collected during the period under review are provided in full in Appendix II.

3.2.1 Stratification

Thermal stratification was weakly developed at both sites during the October 2019 sampling, and was strongly developed during both the February and March 2020 sampling occasions. The lake was isothermal during the June 2020 sampling. The thermocline was located at between 6 m and 12 m depth at site L2 on the sampling occasions, while at site L3 the thermocline location was between 5 m and 7 m below the surface (Figure 3).

Dissolved oxygen stratification was evident at site L3 on all sampling occasions, while at site L2 the dissolved oxygen stratification was strongly developed in February and March 2020 but less pronounced in October 2019 and June 2020 (Figure 3). This pattern of dissolved oxygen stratification remaining site L3 has been typical of Lake Rotorangi in previous monitoring years and indicates that although temperatures are similar throughout the water column, vertical mixing of the water column was not complete.

Surface water temperatures were within the previously recorded ranges during 2019-2020, while water temperatures just above the lake bed were above median during this period.

Surface dissolved oxygen concentrations were within previously recorded ranges, with the exception of site L2 in the spring, where the recorded concentration of 8.1 g/m^3 was the lowest recorded since 1996. Dissolved oxygen concentrations in the water near the lake bed were generally low.

Anoxic conditions, when dissolved oxygen is less than 0.5 g/m^3, was observed in the hypolimnion at site L2, below 22 m in February and March 2020 and below 34 m in June 2020. At site L3 anoxia was recorded below 32 m during February and March 2020 and below 26 m in June 2020.

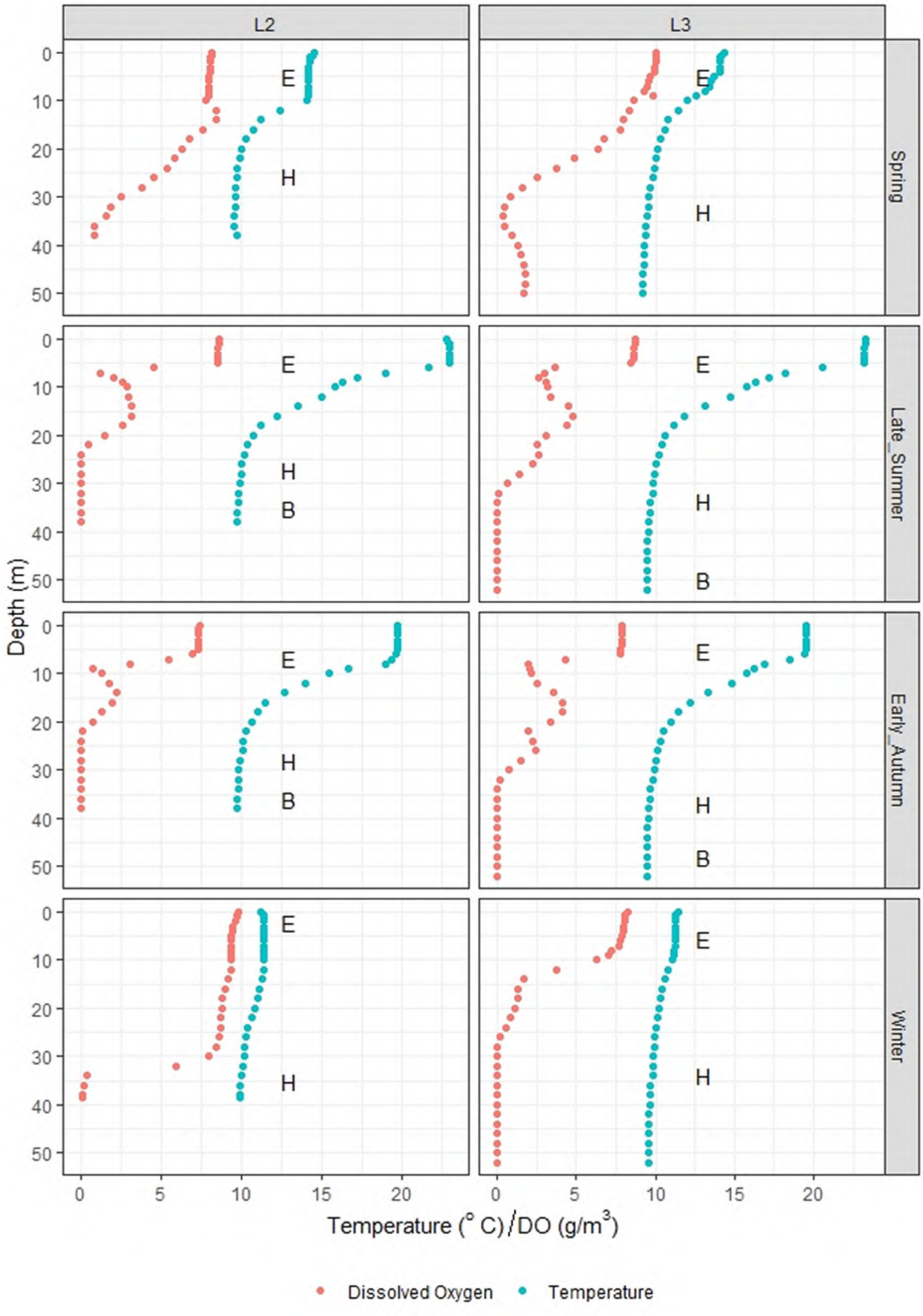


Figure 3 Temperature (°C) and dissolved oxygen (g/m^3) profiles for sites L2 and L3 on sampling occasions in 2019 – 2020. Sampling depths are indicated by letters (E = epilimnion; H = hypolimnion; B = near benthos)

3.2.2 Water chemistry

The full physicochemical monitoring results collected during the period under review are provided in Appendix II. Selected results and associated historical data are discussed in more detail below.

Black disc measurements provide an estimate of horizontal water clarity, while secchi disc provides an estimate of vertical water clarity. Together, these measurements can be used to provide information on the penetration of diffuse light into the water column. As might be expected, there is a direct relationship between the two measurements, with the secchi disc greater than the black disc by a ratio of about 1.2:1 in Lake Rotorangi.

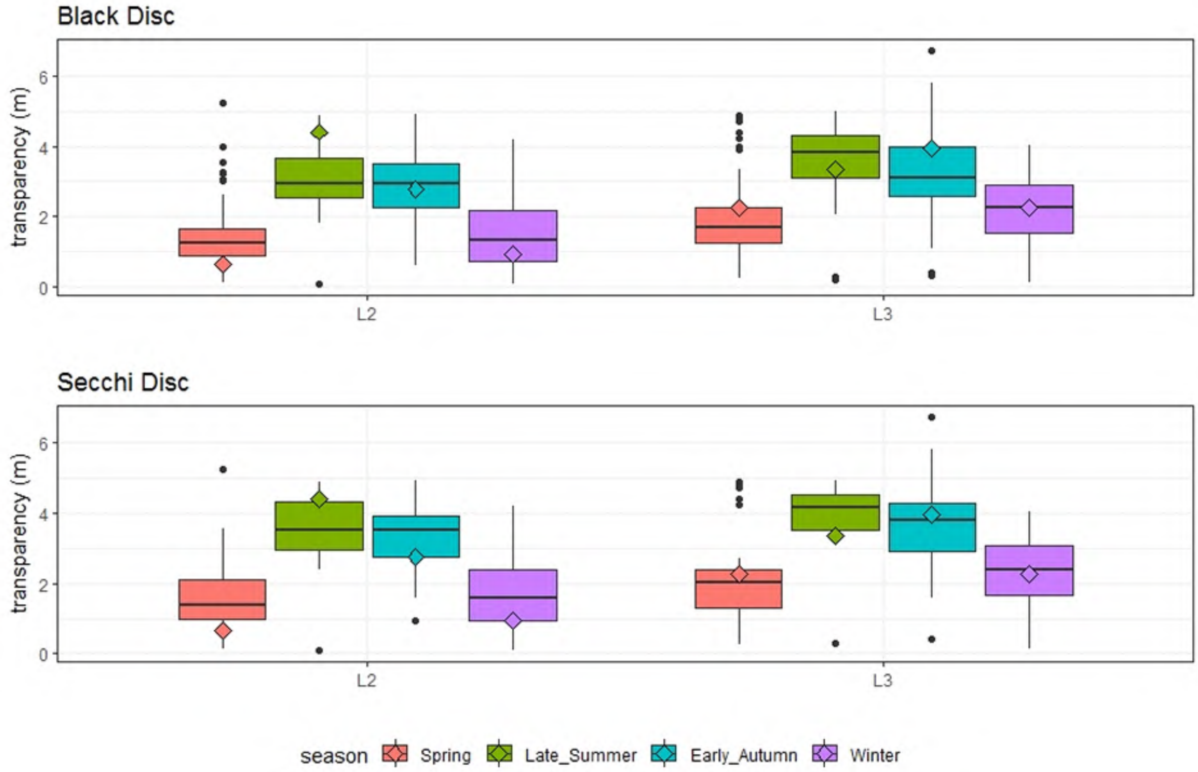


Figure 4 Measures of visual clarity in Lake Rotorangi. Historical summary data for the period 1996-2019 is represented by boxplots, while the measurement recorded in the period under review is represented as a diamond

At site L2, black disc and secchi disc were greater than median values in late summer, and lower than median values for the remainder of the sampling occasions during the year. In contrast, site L3 recorded higher than median back disc and secchi disc in spring and early autumn, and lower than median concentrations in late summer in winter. Both black disc and secchi disc recorded a narrower range at site L3 compared to site L2 during the period under review.

In recognition of the recreational uses of Lake Rotorangi (mainly boating and waterskiing at site L2, but also at site L3; see Taranaki Regional Council, 2008a), samples taken at the surface are tested for E. coli. These results are presented in Figure 5. During the period under review, samples taken at site L2 reached the alert level for primary contact recreation in spring and winter (MfE, 2003), while site L3 had low levels of *E. coli* present on all occasions.

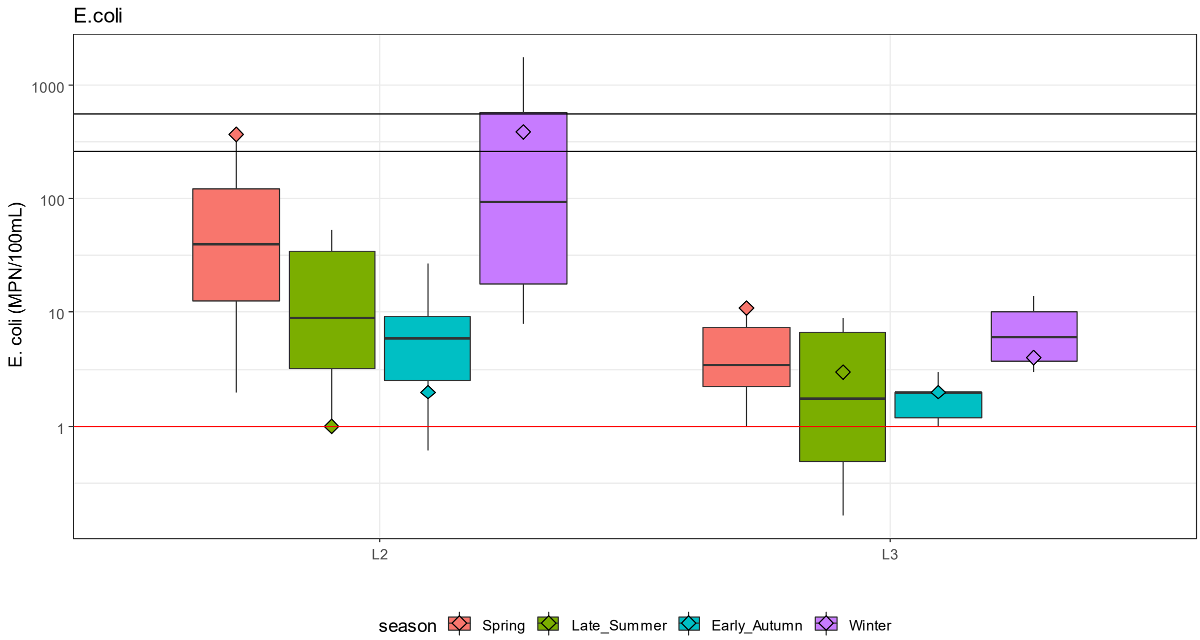


Figure 5 *E. coli* measured at the surface of Lake Rotorangi. Historical summary data for the period 1996-2019 is represented by boxplots, while the measurement recorded in the period under review is represented as a diamond. The red line indicates the threshold below which data is censored. Statistics below this threshold should be interpreted with caution. Black threshold lines represent guidelines for recreational use

Conductivity at site L2 was in the upper quartile of the previously recorded data at the surface and in the epilimnion during the late summer and early autumn (Figure 6). Site L3 recorded conductivity higher than median during the spring, late summer and early autumn sampling. The conductivity in the hypolimnion was in the upper quartile of the previously recorded range at both sites during all four sampling occasions.

Turbidity was slightly elevated at site L2 in spring, while the remainder of the sample results at both sites during the period under review were below or near to median results.

Suspended solids remained at low concentrations at both sites L2 and L3 throughout the period under review. It should be noted that the majority of suspended solids results during this period, including all results from L3, were below the detection limit of this test. Suspended solids data has not been presented in the body of this report due to the extremely high proportion of censored data for this parameter.

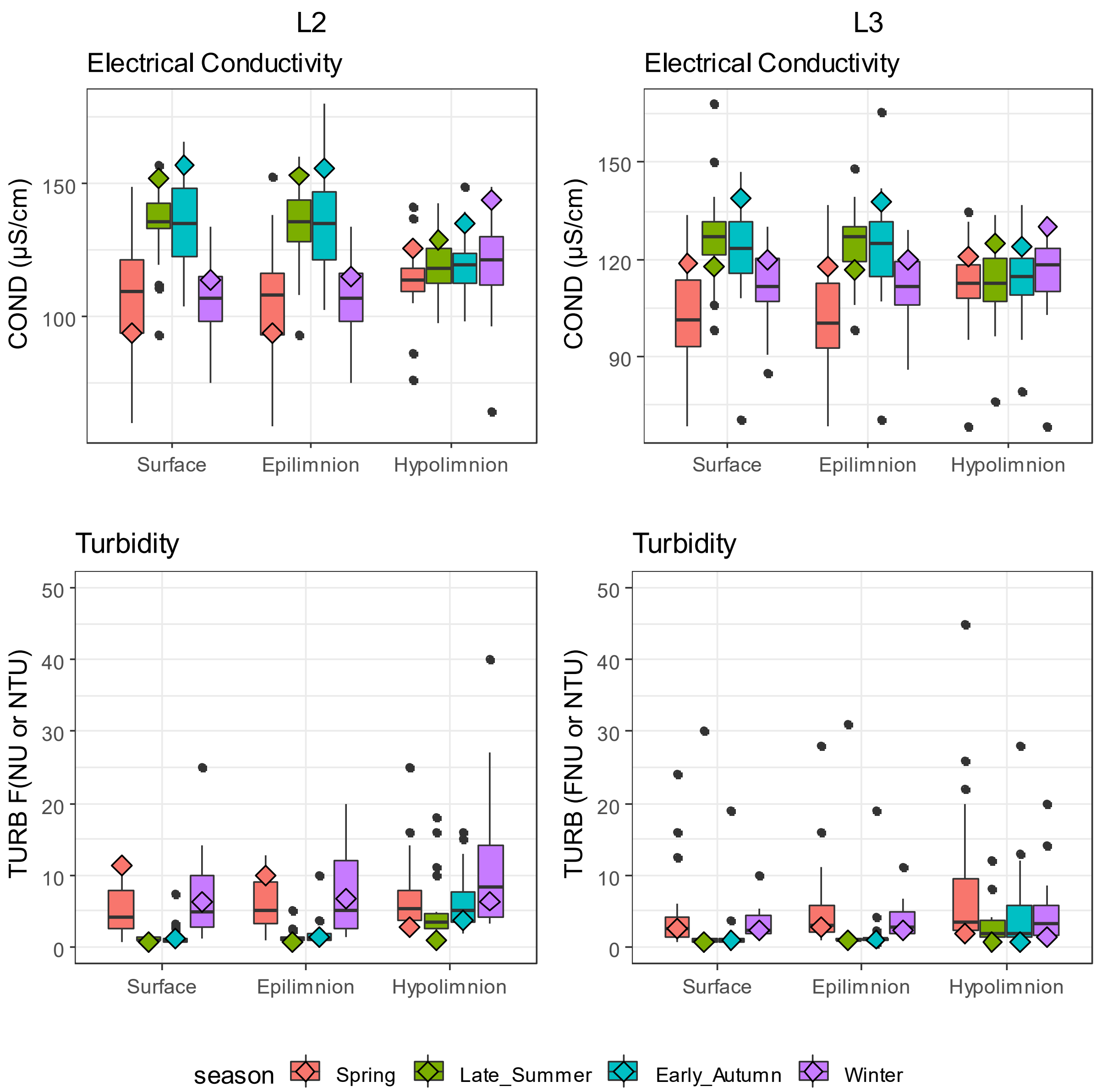


Figure 6 Epilimnetic and hypolimnetic physicochemical parameters in Lake Rotorangi. Historical summary data for the period 1996-2019 is represented by boxplots, while the concentration recorded in the period under review is represented as a diamond

3.2.2.1 Nutrients

Ammoniacal nitrogen was above detection limits at site L2 throughout the period under review, except in the hypolimnion in spring (Figure 7). Nitrate and total nitrogen in the hypolimnion decreased throughout the period under review, while in the epilimnion these parameters were generally within a typical range. Total phosphorus and total Kjeldahl nitrogen were also generally within a typical range, except in spring in the epilimnion when it was slightly elevated compared to typical results. Dissolved reactive phosphorus was also elevated slightly in this sample, while it was fairly typical in the epilimnion for the remainder of the period and showed more variability than typical in the hypolimnion.

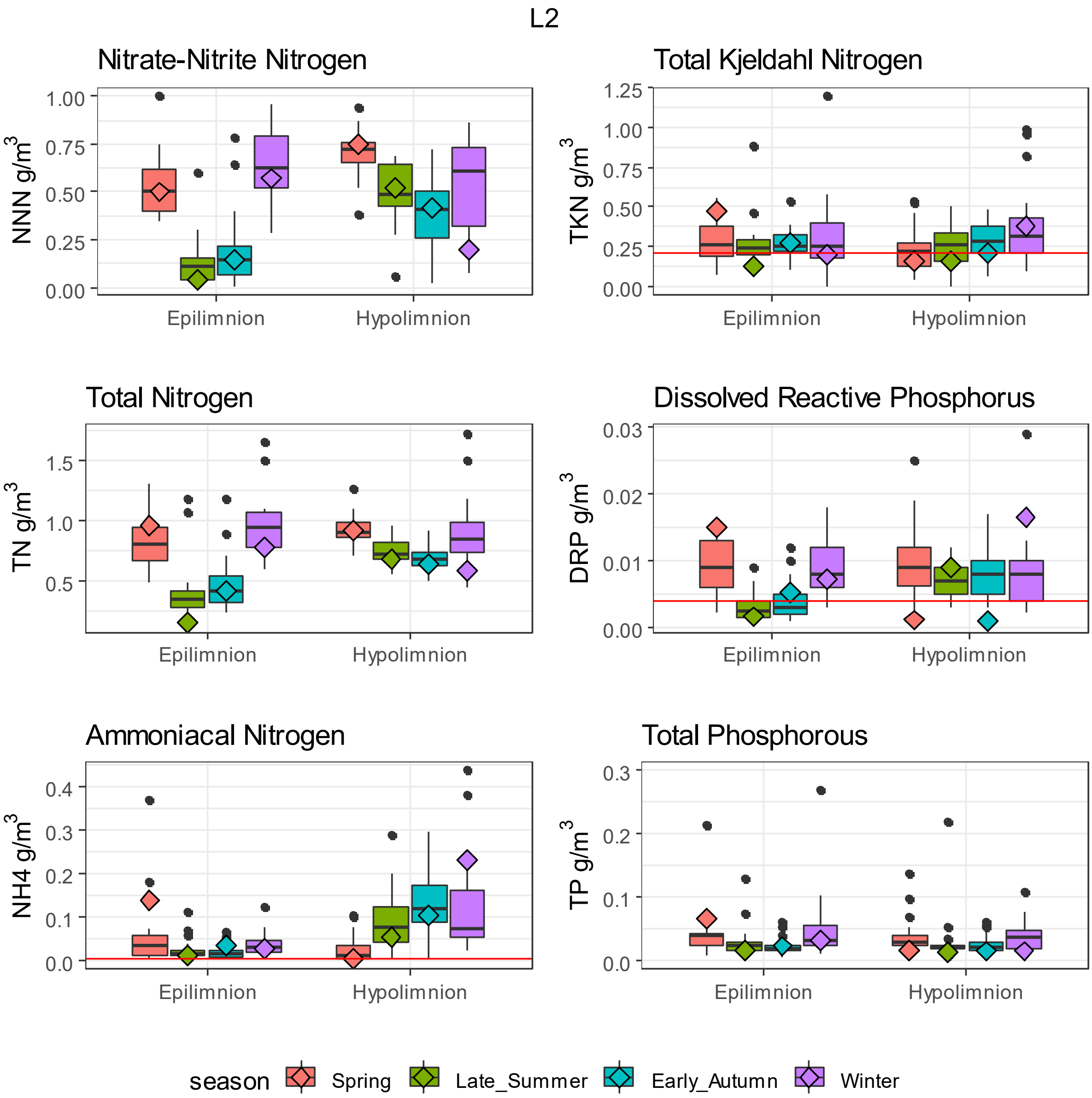


Figure 7 Epilimnetic and hypolimnetic nutrient concentrations at site L2 in Lake Rotorangi. Historical summary data for the period 1996-2019 is represented by boxplots, while the concentration recorded in the period under review is represented as a diamond. Red lines indicate the threshold below which data is censored for each parameter. Statistics below this threshold should be interpreted with caution

Ammoniacal nitrogen at site L3 remained at low concentrations at or around the detection limit in both the epilimnion and hypolimnion (Figure 8). Nitrite nitrogen and dissolved reactive phosphorus concentrations also remained at the detection limit in the hypolimnion, while in the epilimnion nitrite concentrations were below medians throughout the period. Dissolved reactive phosphorus was below detection limits in the epilimnion at the time of the late summer and early autumn sampling (when the lake was stratified), while for the remainder of the year the concentrations remained at fairly typical levels. Total phosphorus and total Kjeldahl nitrogen remained at fairly typical concentration in both the epilimnion and hypoliminion during the period under review.

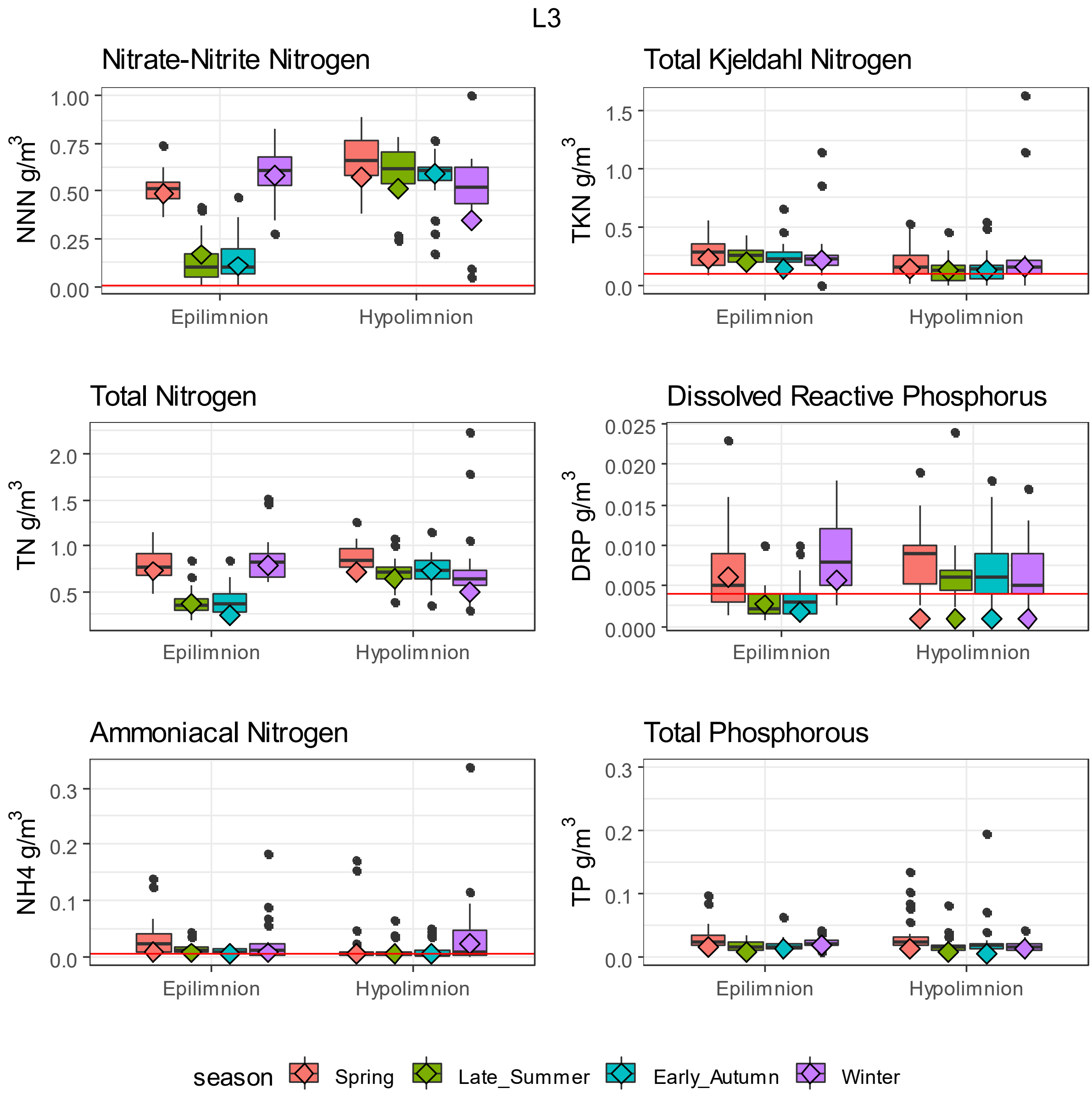


Figure 8 Epilimnetic and hypolimnetic nutrient concentrations at site L3 in Lake Rotorangi. Historical summary data for the period 1996-2009 is represented by boxplots, while the concentration recorded in the period under review is represented as a diamond. Red lines indicate the threshold below which data is censored for each parameter. Statistics below this threshold should be interpreted with caution

The epilimnion recorded relatively low levels of bioavailable nutrients (nitrate and dissolved reactive phosphorus) at both sites L2 and L3 throughout the year. A marked decrease in nitrate and dissolved reactive phosphorus was evident during the stratified period at both sites (Figure 7 and Figure 8). This is typical for Lake Rotorangi and can most likely be attributed to uptake of nutrients by phytoplankton. The dead plant material then sinks into the hypolimnion, and nutrients in the epilimnion are not replenished until overturn occurs resulting in vertical mixing of the water column.

Assessment of total nitrogen and total phosphorus concentrations against the National Objectives Framework (NOF) numeric attribute state (New Zealand Government, 2017) places both sites in the C band for both nitrogen, while both sites sits within the B band for phosphorus (Table 6). It should be noted that Lake Rotorangi is a seasonally stratified lake. This assessment is based on data collected in the epilimnion.

Table 6 Trophic State of Lake Rotorangi based on total nitrogen and total phosphorus National Objective Framework attributes. (Note that units used in the NOF differ from the units primarily used throughout this report)

Parameter	Site	Median (mg/m^3)	Band	Narrative Attribute State
Total Nitrogen	L2	605	C	Lake ecological communities are moderately impacted by additional algal and plant growth arising from nutrient levels that are elevated well above natural reference conditions
	L3	670	C	Lake ecological communities are moderately impacted by additional algal and plant growth arising from nutrient levels that are elevated well above natural reference conditions
Total Phosphorus	L2	15.5	B	Lake ecological communities are slightly impacted by additional algal and plant growth arising from nutrient levels that are elevated above natural reference conditions
	L3	9.5	B	Lake ecological communities are slightly impacted by additional algal and plant growth arising from nutrient levels that are elevated above natural reference conditions

3.2.2.1.1 Sediment/water interface

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 taken for nutrients at bottom of water column during stratified periods since 1996. Over this time period, the data has 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. At site L2 no change has been seen in phosphorus levels, while at site L3 an increase in total phosphorus has been observed near the lakebed, in conjunction with an increase in turbidity. This is likely related to disturbance of the lakebed during sampling rather than hypoxic nutrient release because no such increase in DRP is observed.

Anoxic conditions were present at both sites during the late summer and early autumn sampling in the hypolimnion as well as near the bottom of the water column. Ammonia concentrations at both sites L2 and L3 were elevated in the water column near the lakebed compared to higher in the hypolimnion (Figure 9 and Figure 10). At site L3 there was a noticeable decrease in nitrate lower in the water column. When considered in conjunction with the increase in ammonia, this indicates that reduction of nitrogen may be occurring in the anoxic conditions present. DRP concentrations remained largely similar, or were at lower concentrations, in the water column near the lakebed compared to higher in the hypolimnion. Both total phosphorus and turbidity were relatively low in the hypolimnion and near the lake bed at both sites.

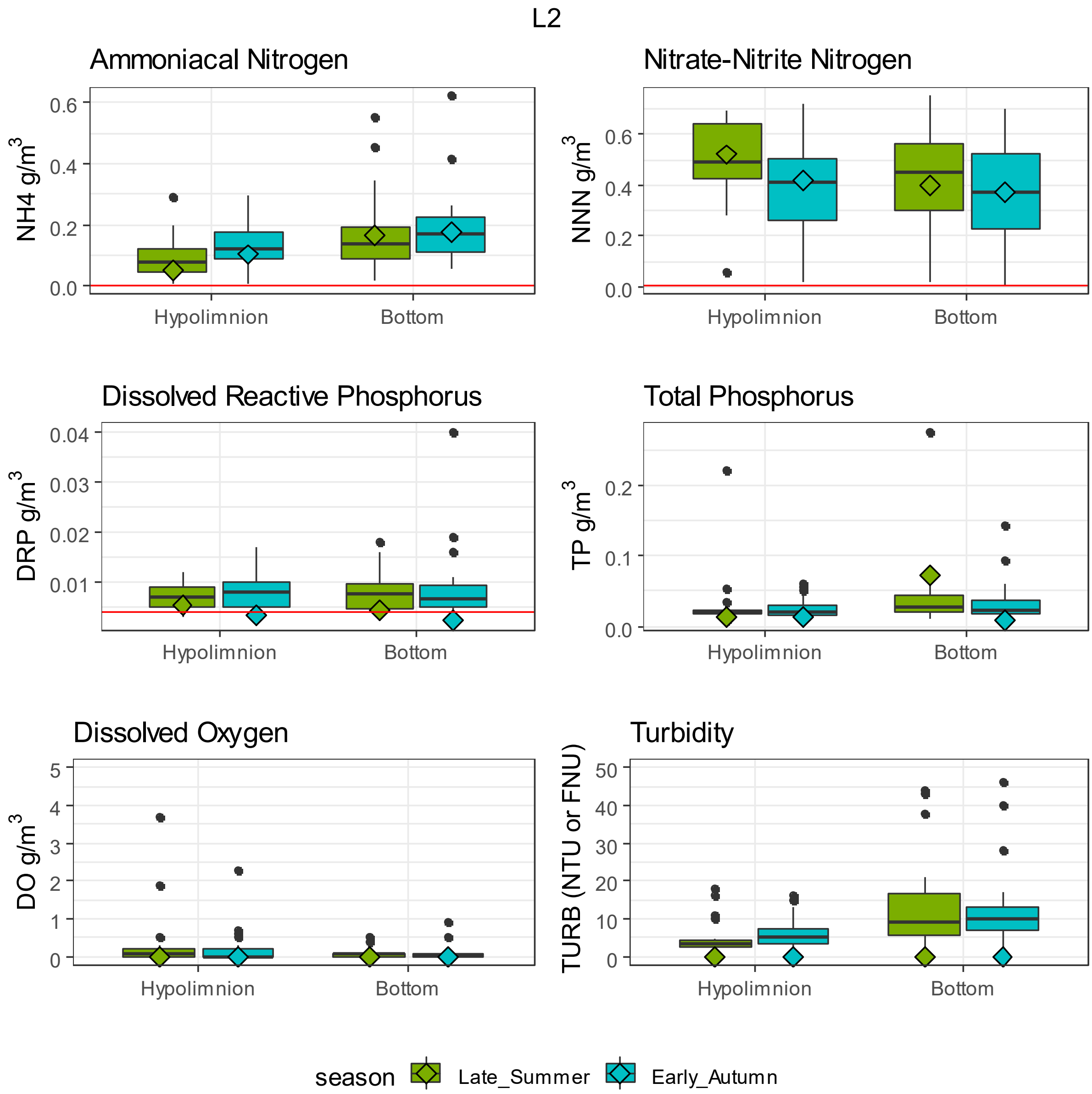


Figure 9 Selected parameters sampled in Lake Rotorangi in the hypolimnion and near the bottom of the water column at site L2. Historical summary data for the period 1996-2019 is represented by boxplots, while the concentration recorded in the period under review is represented as a diamond. Red lines indicate the threshold below which data is censored for each parameter. Statistics below this threshold should be interpreted with caution

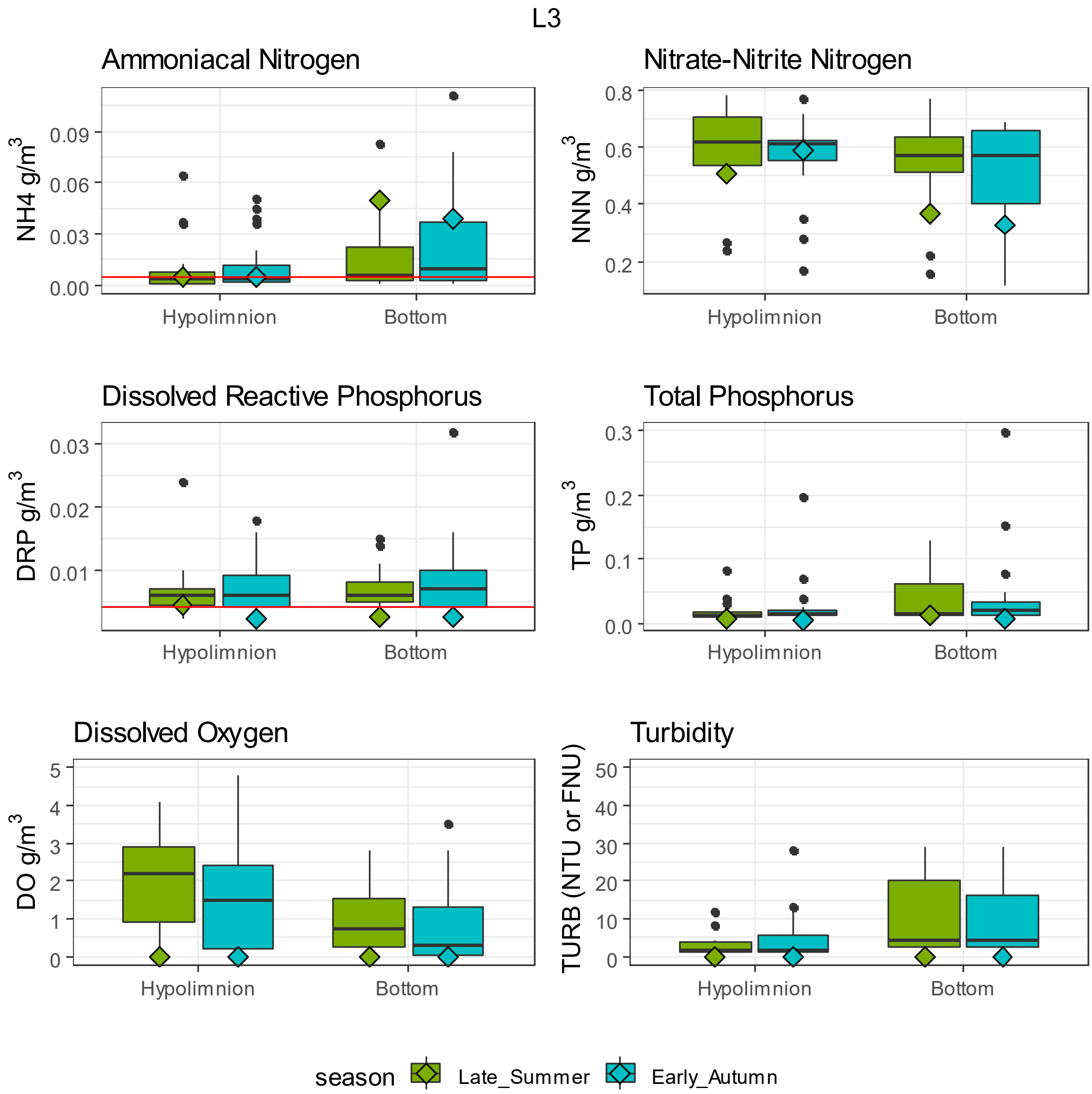


Figure 10 Selected parameters sampled in Lake Rotorangi in the hypolimnion and near the bottom of the water column at site L3. Historical summary data for the period 1996-2009 is represented by boxplots, while the concentration recorded in the period under review is represented as a diamond. Red lines indicate the threshold below which data is censored for each parameter. Statistics below this threshold should be interpreted with caution

3.3 Biological

3.3.1 Phytoplankton

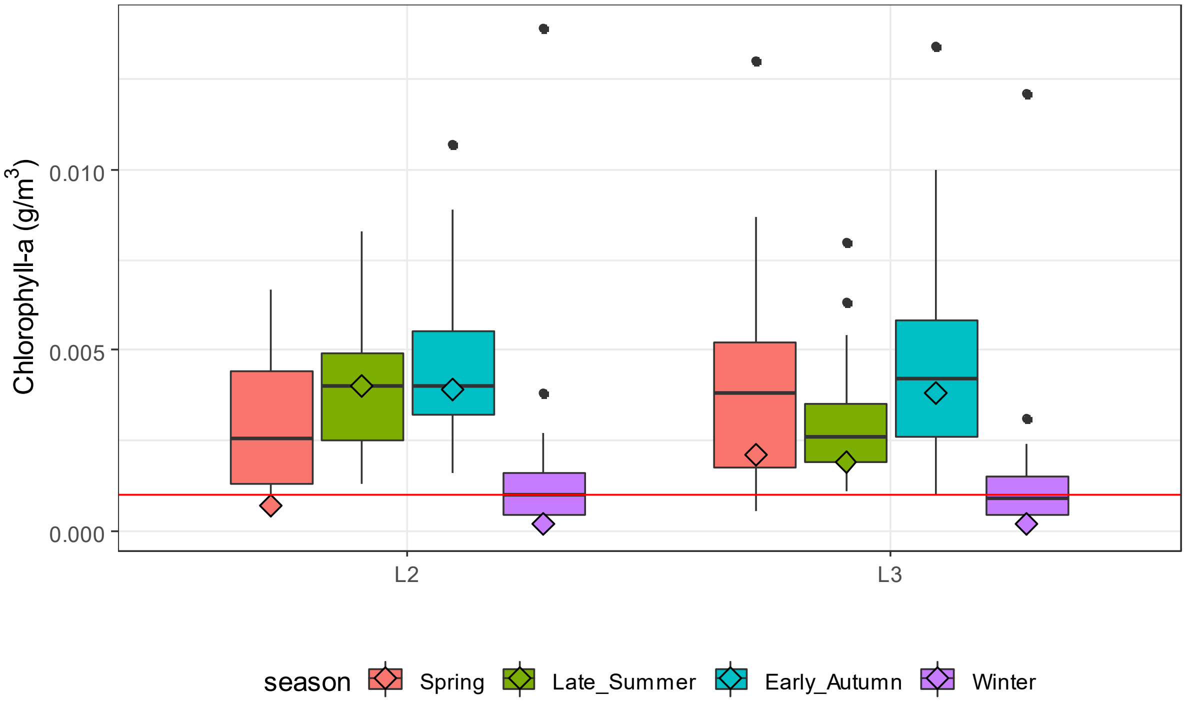


Figure 11 Seasonal chlorophyll-a concentrations in the photic zone of Lake Rotorangi. Historical summary data is represented by boxplots, while the concentration recorded in the period under review is represented as a diamond. Red lines indicate the threshold below which data is censored for each parameter. Statistics below this threshold should be interpreted with caution

Chlorophyll-a concentrations during the period under review were within the previously recorded ranges and were equal to or less than the median concentrations (Figure 11). In winter 2020, both site L2 and site L3 recorded concentrations below the detection limit.

Assessment of chlorophyll concentrations in Lake Rotorangi based on three years of data against the phytoplankton NOF attribute places both sites in the B band for phytoplankton (Table 1 and Table 7) (New Zealand Government, 2017).

Table 7 Phytoplankton attribute state of Lake Rotorangi under the National Objectives Framework. (Note that units used in the NOF differ from the units primarily used throughout this report)

Site	Median (mg/m³)	Maximum (mg/m³)	Band	Narrative Attribute State
L2	3.6	10.7	B	Lake ecological communities are slightly impacted by additional algal and/or plant growth arising from nutrient levels that are elevated above natural reference conditions
L3	2.9	13.0	B	Lake ecological communities are slightly impacted by additional algal and/or plant growth arising from nutrient levels that are elevated above natural reference conditions

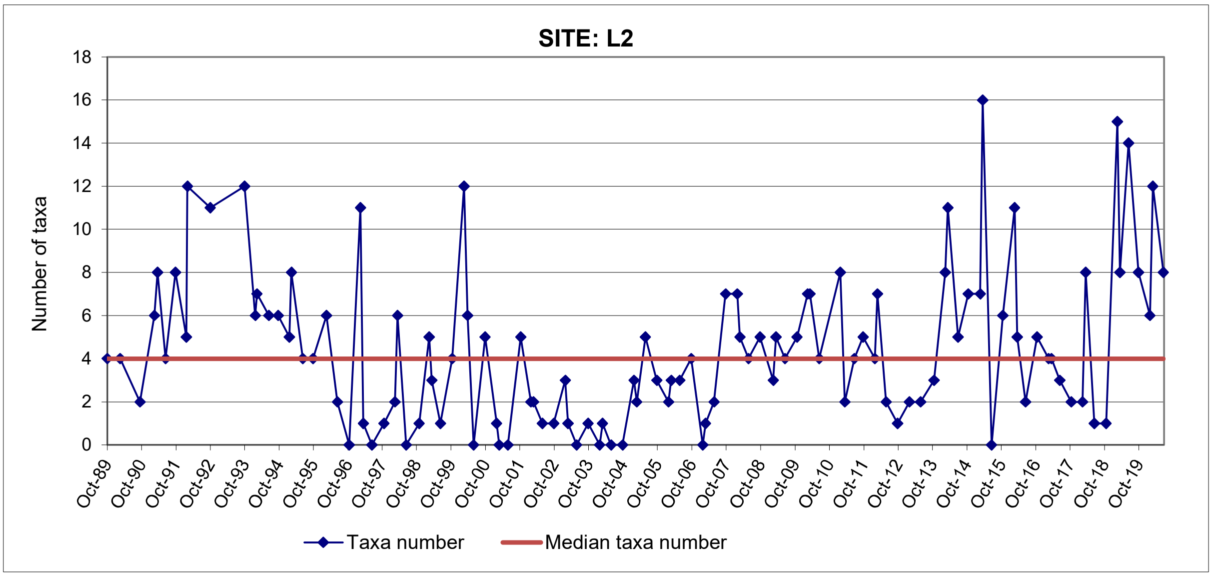


Figure 12 Phytoplankton taxa richness at site L2 since 1989

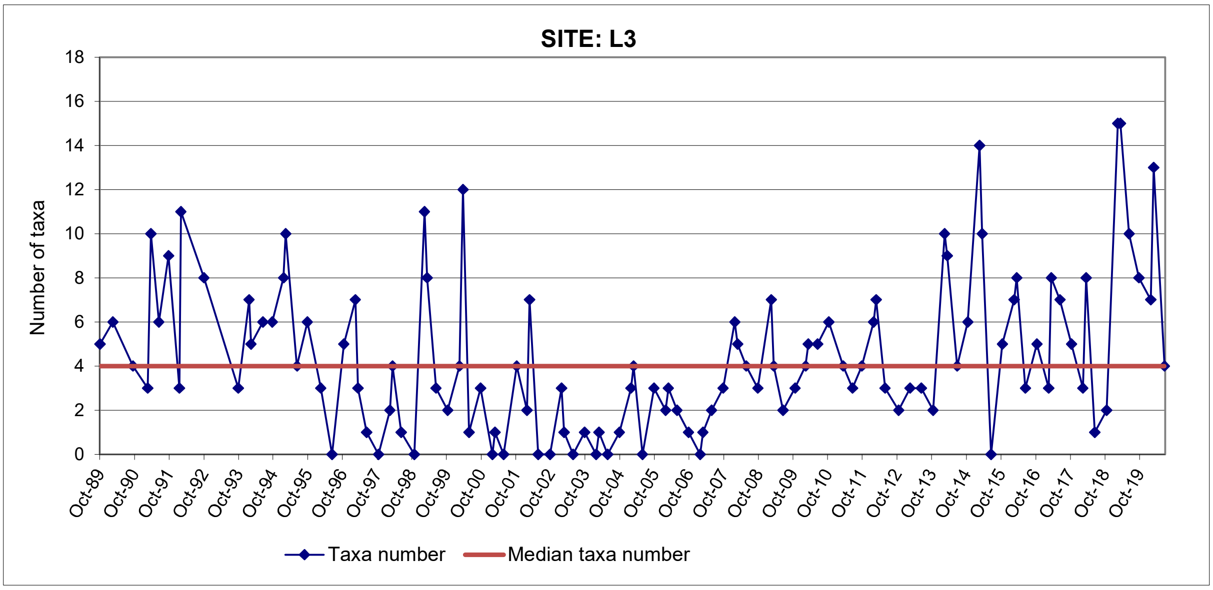


Figure 13 Phytoplankton taxa richness at site L3 since 1989

Phytoplankton taxa richness was higher than has been typical for both sites L2 and L3 during the 2019-2020 period (Figure 12 and Figure 13). Richness was between 6 and 12 taxa at site L2, and 4 and 13 taxa at site L3.

3.3.2 Benthic macroinvertebrates

Macroinvertebrate sampling was last undertaken in October 2017. This is next scheduled for the 2020-2021 monitoring year. The results of the October 2017 macroinvertebrate survey are discussed in full in the 2016-2018 Lake Rotorangi water quality and biological monitoring report (TRC 2018).

3.3.3 Macrophytes

The macrophyte survey was last undertaken in April 2018. This is next scheduled for the 2020-2021 monitoring year. The results of the April 2017 macrophyte survey are discussed in full in the 2016-2018 Lake Rotorangi water quality and biological monitoring report (TRC 2018).

3.4 Trophic state

The trophic state of Lake Rotorangi is shown in Table 8. Annual trophic level values are provided in Appendix III for the lake as a whole and for the individual sites. The trophic level for the year under review was 4.04 TLI units, classifying the lake as eutrophic. When the individual components of the TLI are considered, chlorophyll-a concentrations categorise the lake as mesotrophic, while secchi depth, total nitrogen and total phosphorus categorise the lake as eutrophic. This is consistent with previous observations, which note that the trophic status of the lake is influenced by turbidity.

When the trophic status is examined for the sites individually, site L2 is classed as mesotrophic while site L3 is eutrophic.

Table 8 Trophic level and values of key variables defining the trophic status* of Lake Rotorangi in 2019-2020. (Note that units used in the trophic level calculations differ from the units primarily used throughout this report)

Trophic Level Component	Unit	L2	L3	Whole Lake
Overall Trophic Status		Eutrophic	Mesotrophic	Eutrophic
Trophic Level	TLI units	4.23	3.80	4.04
Chlorophyll a	mg m^{-3}	2.17 (M)	1.97 (O)	2.08
Secchi Depth	m	2.19 (E)	2.95 (M)	2.57
Total Nitrogen	mg N m^{-3}	549 (E)	494 (E)	521
Total Phosphorus	mg P m^{-3}	31.5 (E)	13.0 (M)	22.3

* Letters in brackets relate to the trophic status of individual trophic level components. O=Oligotrophic, M=Mesotrophic, E=Eutrophic

The trophic level of Lake Rotorangi has shown an increase over time (Figure 14), albeit at a very slow rate of change (see Table 9). The loess curve shown in Figure 14 shows distinct peaks in 2004 and 2015, both years in which flood inflows affected the water chemistry of the lake, and illustrates the relatively riverine nature of Lake Rotorangi.

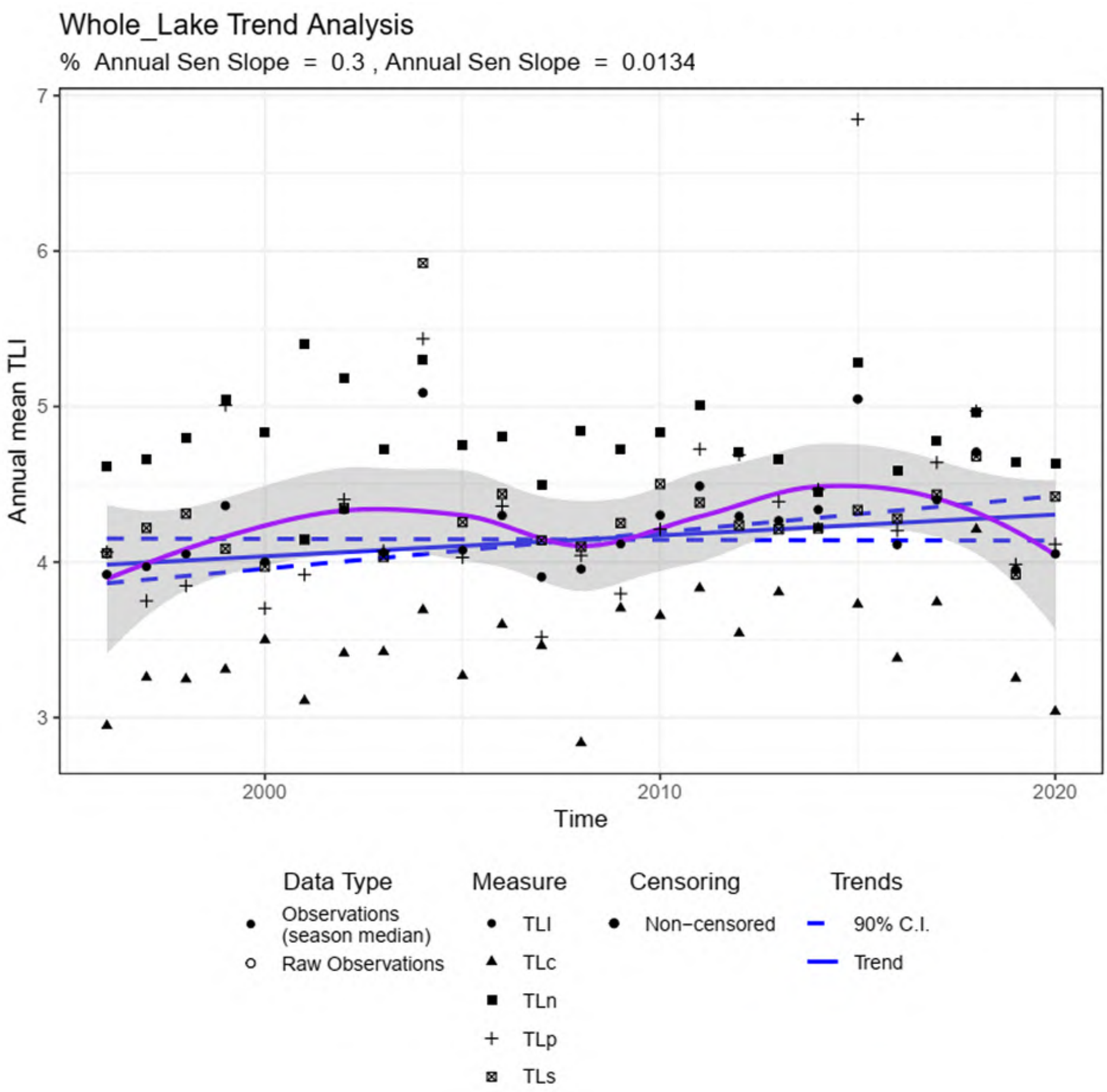


Figure 14 Trophic level index in Lake Rotorangi over the period 1996-2020. The four components of the TLI (chlorophyll-a, secchi depth, total nitrogen and total phosphorus) are plotted individually, as well as the overall TLI. The trend shown relates to the overall TLI. The lowess curve for the overall TLI is in purple

3.5 Temporal trends

Where possible, trend analysis is carried out based upon data from the epilimnion. In the case of chlorophyll-a and secchi distance, which are not measured in the epilimnion, data is from the photic zone and surface, respectively. Hypolimnetic data is not trended due to the magnitude of change occurring seasonally as a result of stratification processes, which has the potential to mask changes in the data over longer time frames. This is consistent with national analyses (Larned *et al.*, 2015).

Trend analysis results for the period 1996-2020 are provided in Table 9, and for the most recent ten years (2010-2020) in Table 10. Although it is typical to report statistical analysis for a lake holistically, the riverine nature of Lake Rotorangi means that there are substantial differences in water chemistry between the mid and lower lake sites. Therefore, the trend analysis for the whole lake should be interpreted with caution.

Trend plots for each variable are provided in Appendix IV for the period 1996-2020 and Appendix V for the period 2011-2020.

Table 9 Trend analysis of selected variables in Lake Rotorangi for the period 1996-2020. Trends of high confidence are identified in red (degrading trend) or blue (improving trend)

Measure	Site	No. of Surveys	Seasonality	Proportion censored	Median Slope	Percent Annual Change	Trend	Confidence (%)
CHLA	L2	98	Seasonal	0.16	0.00005	1.79	Very Likely Degrading	99.60
	L3	98	Seasonal	0.13	0.00004	1.70	Very Likely Degrading	99.50
	Whole Lake	98	Seasonal	0.10	0.00006	2.06	Very Likely Degrading	99.94
COND	L2	100	Seasonal	0.00	2.75994	0.23	Likely Degrading	89.03
	L3	100	Seasonal	0.00	3.79836	0.32	Very Likely Degrading	98.65
	Whole Lake	100	Seasonal	0.00	3.15944	0.27	Very Likely Degrading	98.68
DRP	L2	100	Seasonal	0.34	0.00000	0.00	Indeterminate	55.05
	L3	100	Seasonal	0.45	0.00000	0.00	Very Likely Improving	92.27
	Whole Lake	100	Seasonal	0.38	0.00000	0.00	Indeterminate	61.16
NH4	L2	100	Seasonal	0.10	0.00000	0.00	Indeterminate	50.00
	L3	100	Seasonal	0.17	-0.00027	-2.48	Very Likely Improving	98.46
	Whole Lake	100	Seasonal	0.01	-0.00015	-0.85	Likely Improving	79.33
NNN	L2	92	Seasonal	0.00	-0.00138	-0.37	Likely Improving	78.25
	L3	92	Seasonal	0.02	0.00000	0.00	Indeterminate	51.06
	Whole Lake	92	Seasonal	0.00	-0.00066	-0.17	Indeterminate	62.44
SECCHI	L2	100	Seasonal	0.00	-0.00892	-0.33	Likely Degrading	73.59

Measure	Site	No. of Surveys	Seasonality	Proportion censored	Median Slope	Percent Annual Change	Trend	Confidence (%)
	L3	100	Seasonal	0.00	-0.00767	-0.25	Likely Degrading	76.58
	Whole Lake	100	Seasonal	0.00	-0.00333	-0.11	Indeterminate	61.04
TLI	L2	25	NonSeasonal (Annual Mean)	0.00	0.01047	0.25	Very Likely Degrading	95.59
	L3	25	NonSeasonal (Annual Mean)	0.00	0.01204	0.29	Very Likely Degrading	91.59
	Whole Lake	25	NonSeasonal (Annual Mean)	0.00	0.01342	0.32	Very Likely Degrading	93.55
TN	L2	100	Seasonal	0.00	-0.00500	-0.80	Very Likely Improving	98.80
	L3	100	Seasonal	0.00	-0.00495	-0.81	Very Likely Improving	98.94
	Whole Lake	100	Seasonal	0.00	-0.00500	-0.80	Very Likely Improving	99.53
TP	L2	100	Seasonal	0.00	0.00057	2.31	Very Likely Degrading	99.99
	L3	100	Seasonal	0.00	0.00016	0.84	Very Likely Degrading	93.30
	Whole Lake	100	Seasonal	0.00	0.00041	1.79	Very Likely Degrading	99.86
TURB	L2	100	Seasonal	0.00	0.02227	0.97	Very Likely Degrading	94.79
	L3	100	Seasonal	0.00	0.00909	0.61	Likely Degrading	86.41
	Whole Lake	100	Seasonal	0.00	0.01484	0.82	Very Likely Degrading	93.11

Improving trends in total nitrogen were detected with high confidence at both sites L2 and L3 and for the lake as a whole, albeit at a relatively slow rate of change of 0.8 % (or 0.04 and 0.05 g N m^{-3} at L2 and L3 respectively) per year.

Both sites show a degrading trend in chlorophyll-a, with increases of approximately 1.7-1. 8% per year. For the lake as a whole, a similar trend is detected, with a change of more than 2 % per year. This long-term increasing trend in chlorophyll-a merits further attention, although given the low levels of chlorophyll-a in the lake currently this increase is roughly 0.00005 g m^{-3} per year.

A degrading trend in conductivity was detected with high confidence at site L3 and for the lake as a whole, however the magnitude of this trend is relatively minor at around 0.3 % per year.

Site L2, and the lake as a whole show degrading trends of high confidence for total phosphorus, with an increase of approximately 1.8 % per year for the lake as a whole. Ammonia is decreasing at a rate of approximately 2.5 % per year at site L3, however, at site L2 results suggest the level is remaining relatively steady. While there is a degrading trend for the lake as a whole, this result is detected with low confidence and shouldn't be read into too deeply.

The trophic level index shows an increasing trend of high confidence at site L2. An increasing trend was also detected for site L3 and the lake as a whole, but with a relatively lower level of confidence in the result. It should be noted that because this is a calculation resulting in one annual data point, the ability to detect a trend is reduced compared to parameters which are sampled four times a year. Consequently a ten year trend has not been calculated for the TLI due to insufficient data.

Table 10 Trend analysis of selected variables for Lake Rotorangi over the most recent ten year period (2011-2020). Trends of high confidence are identified in red (degrading trend) or blue (improving trend)

Measure	Site	No. of Surveys	Seasonality	Proportion censored	Median Slope	Percent Annual Change	Trend	Confidence (%)
CHLA	L2	38	Seasonal	0.13	-0.00007	-1.95	Likely Improving	83.56
	L3	38	Seasonal	0.11	-0.00020	-5.92	Very Likely Improving	96.79
	Whole Lake	38	Seasonal	0.11	-0.00014	-3.86	Very Likely Improving	93.43
COND	L2	40	Seasonal	0.00	9.52249	0.79	Likely Degrading	85.87
	L3	40	Seasonal	0.00	21.00697	1.79	Very Likely Degrading	99.64
	Whole Lake	40	Seasonal	0.00	15.08232	1.29	Very Likely Degrading	99.22
DRP	L2	40	Seasonal	0.38	0.00000	0.00	Likely Improving	83.01
	Whole Lake	40	Seasonal	0.32	0.00000	0.00	Likely Improving	87.00
NH4	L2	40	Non-Seasonal	0.15	0.00097	4.60	Likely Degrading	77.28
	L3	40	Non-Seasonal	0.20	-0.00011	-1.34	Likely Improving	82.12

Measure	Site	No. of Surveys	Seasonality	Proportion censored	Median Slope	Percent Annual Change	Trend	Confidence (%)
	Whole Lake	40	Non-Seasonal	0.00	0.00014	0.93	Indeterminate	61.02
NNN	L2	40	Seasonal	0.00	-0.00500	-1.30	Likely Improving	77.65
	L3	40	Seasonal	0.05	0.00000	0.00	Indeterminate	51.79
	Whole Lake	40	Seasonal	0.00	-0.00501	-1.21	Indeterminate	62.31
SECCHI	L2	40	Seasonal	0.00	-0.00123	-0.04	Indeterminate	50.00
	L3	40	Seasonal	0.00	0.04425	1.36	Likely Improving	82.67
	Whole Lake	40	Seasonal	0.00	0.01507	0.49	Indeterminate	65.63
TLI	L2	10	NonSeasonal (Annual Mean)	0.00	-0.03340	-0.75	Likely Improving	81.45
	L3	10	NonSeasonal (Annual Mean)	0.00	-0.04568	-1.09	Likely Improving	81.45
	Whole Lake	10	NonSeasonal (Annual Mean)	0.00	-0.04521	-1.05	Likely Improving	81.45
TN	L2	40	Seasonal	0.00	-0.01164	-1.89	Likely Improving	84.91
	L3	40	Seasonal	0.00	-0.00873	-1.51	Likely Improving	84.91
	Whole Lake	40	Seasonal	0.00	-0.01116	-1.93	Very Likely Improving	90.31
TP	L2	40	Non-Seasonal	0.00	-0.00099	-3.15	Likely Improving	83.92
	L3	40	Seasonal	0.00	-0.00171	-7.95	Very Likely Improving	99.85
	Whole Lake	40	Seasonal	0.00	-0.00137	-5.23	Very Likely Improving	97.56

Measure	Site	No. of Surveys	Seasonality	Proportion censored	Median Slope	Percent Annual Change	Trend	Confidence (%)
TURB	L2	40	Seasonal	0.00	0.01083	0.47	Indeterminate	53.57
	L3	40	Seasonal	0.00	-0.04257	-3.04	Very Likely Improving	90.31
	Whole Lake	40	Seasonal	0.00	-0.00700	-0.39	Indeterminate	55.34

Over the most recent ten year period, decreasing trends of relatively low confidence were found in chlorophyll-a for the lake as a whole, and at site L3. The magnitude of this trend is relatively large, at approximately 6 % per year. This is in contrast to the long-term increasing trends found in chlorophyll-a.

Conductivity showed a similar pattern in the short term trend as over the longer record, although the magnitude of the trend over the shorter term was much greater, at around 1.3 % for the lake as a whole.

An improving trend with very high confidence was detected in total phosphorous at site L3, and for the lake as a whole. The magnitude of this trend is significant, with a decrease of approximately 8 % per year at site L3 and for the whole lake. This is in contrast with the 25 year trend where total phosphorus is increasing, and occurs in conjunction with an improving trend in turbidity at this site.

4 Discussion

During the period under review stratification was recorded in Lake Rotorangi at both the mid and lower sites in late summer and early autumn. Anoxia was recorded in the hypolimnion in both late summer and early autumn. Overturn was complete at site L2 and only partially complete at site L3 by the time of the winter sampling.

The anoxic conditions in the lower hypolimnion have the potential to result in the release of nutrients from the lakebed sediments, particularly during periods when the lake is stratified. Monitoring of the water column near the lakebed during the stratified period shows very slight increases in ammonia concentrations and very slight decreases in nitrate concentrations compared to higher in the hypolimnion. Dissolved reactive phosphorus concentrations do not show any increase lower in the water column. 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). There is insufficient evidence to conclude whether hypoxic nutrient release is occurring in Lake Rotorangi, however given the small magnitude of the changes in water chemistry this is considered unlikely.

Total phosphorus showed an improving trend at site L3, and total nitrogen showed a decreasing trend at both sites L2 and L3. All other nutrients measured did not show any trend over time at individual sites. It is worth noting that because of the low nutrient concentrations in Lake Rotorangi, several parameters have a large amount of censored data, impacting upon the ability to determine the change over time. This is particularly relevant for suspended solids, which has been removed from the trend analysis because approximately two-thirds of the data is censored.

When only the most recent ten years of data is considered, total phosphorus shows an improving trend at site L3 and conductivity shows a degrading trend at this site, while the remainder of the nutrients did not show a trend with any confidence at an individual site over this period.

Chlorophyll concentrations in Lake Rotorangi remain relatively low, as does phytoplankton species diversity. However, trend analysis indicates that chlorophyll- a concentrations are increasing over time at both sites L2 and L3. However, the rate of change at both sites is less than 2 % per year, and based on the current annual medians, at site L3 chlorophyll-a concentrations would need to increase by more than double to reach eutrophic status based on this parameter (Burns, 1999; Appendix III). Site L2 currently has chlorophyll-a concentrations around the oligotrophic/mesotrophic boundary. Interestingly, the shorter term trend shows improving chlorophyll-a concentrations in Lake Rotorangi, with a high level of confidence at site L3.

The trends for Lake Rotorangi have been calculated for the lake as a whole as well as for the individual sites. It is typical to analyse lakes holistically, however Lake Rotorangi is quite riverine in nature and this is more pronounced at the mid lake site compared to the lower lake site. This leads to differences in the water chemistry and ecology between the sites which makes the individual site analysis potentially more insightful than the analyses of the whole lake.

The trends for the lake as a whole showed degrading chlorophyll-a, conductivity and total phosphorus; and improving total nitrogen over the 25 year record. In contrast, the most recent ten year period shows an degrading trend in conductivity and an improving trend in total phosphorus over this period. It is likely that the total phosphorus levels are related to the suspended sediment within the water column. However, the high amount of censored data for suspended solids prevents analysis of any correlation between these parameters.

Ecosystem health is assessed on the basis of NOF attributes and classifies the lake as being in a mildly impacted state. This is based upon total phosphorus and chlorophyll-a concentrations. Total nitrogen concentrations class the lake as being in a moderately impacted state. This is congruent with previous observations which class the lake as being mildly phosphorus limited. (Burns, 2006).

The most recent macrophyte survey, in 2018 recorded several invasive species, including hornwort (*Ceratophyllum demersum*). While the effects on the ecology of Lake Rotorangi and the hydroelectric scheme are not anticipated to be significant, there is the potential for spread to other lakes where the effects may be more 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 2015-2016 monitoring year to include specific reference to hornwort.

4.1 Changes to data analysis from previous reporting

Significant changes to the data analysis methodology have been made in the current report. Previously LakeWatch software has been used for analysis and it is no longer being supported. Moving away from using the LakeWatch analysis software has provided the opportunity to review and update the analytical methods used. A summary of the main changes can be found in Appendix VII.

Overall, these changes have had the effect that the parameters for which a significant trend has been reported have changed. A comparison between the results of the confidence grading system and the previous p-value based significance method is also given in Appendix VI. This analysis shows that the confidence based system identifies the same trends as the significance based system, when the statistical output is interpreted correctly. A further analysis is provided in Appendix VII, identifying the changes in reported trends compared to previous reporting periods where the p-value of the f-statistic was incorrectly reported. This shows that between the two periods there are few similarities in reported trends, with only chlorophyll-a at all sites, TLI at site L2 and total phosphorus for the whole lake showing increasing trends in both analyses. Previous reporting did not detect any decreasing trends, which is due to the interpretation of trends in previous years. It should also be noted that the parameters used in the trend analysis have changed slightly, with turbidity now included in the analysis and suspended solids, dissolved oxygen and temperature no longer trended.

5 Recommendations

The following recommendations are based on the results of the 2019-2020 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.

Glossary of common terms and abbreviations

The following abbreviations and terms are used within this report:

anoxia	absence of dissolved oxygen (defined as dissolved oxygen concentrations less than 0.5 g/m^3)
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 25°C and expressed in µS/cm
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
FNU	formazin nephelometric unit, a measure of the turbidity of water
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
imputed value	a calculated estimate of value produced when an exact value cannot be obtained
isothermal	thermally mixed lake; defined in this report as less 3°C difference in water temperature between the lake surface and lake bottom
L/s	litres per second
mesotrophic	intermediate condition of nutrient enrichment between oligotrophic and eutrophic in lakes
mS/m	millisiemens per metre
µS/cm	microsiemens per centimetre.
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	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
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
TLI	trophic level index, a method of measuring the trophic level of a lake
trophic level	amount of nutrient enrichment of a lake
turb	turbidity, expressed in NTU or FNU
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

Bibliography and references

Burns NM, 1995. *Results of monitoring the water quality of Lake Rotorangi.* NIWA Consultancy Report TRC 302.

Burns NM, Rutherford CJ, & Clayton JS, 1999. *A monitoring and classification system for New Zealand lakes and reservoirs*. Lake and Reservoir Management 15: 255-271.

Burns NM, 1999. *The trophic status of Lake Rotorangi.* Lakes Consulting Client Report: 99/2.

Burns NM, Bryers G, & Bowman E, 2000. *Protocol for monitoring trophic levels of New Zealand lakes and Reservoirs*. Ministry for the Environment, Wellington. 122pp.

Burns NM, 2006. *Water quality trends in Lake Rotorangi, 1990-2006*. Lakes Consulting Client Report 2006/2.

Greenland S, Senn SJ, Rothman KJ, Carlin JB, Poole C, Goodman SN and Altman DG, 2016. *Statistical tests, P values, confidence intervals, and power: a guide to misinterpretations*. European journal of epidemiology, 31(4), pp.337-350.

Helsel, D.R., Hirsch, R.M., Ryberg, K.R., Archfield, S.A. and Gilroy, E.J., 2020. Statistical methods in water resources (No. 4-A3). US Geological Survey.

Helsel, D.R., 2011. Statistics for censored environmental data using Minitab and R (Vol. 77). John Wiley & Sons.

Hirsch, R.M., Slack, J.R. and Smith, R.A., 1982. *Techniques of trend analysis for monthly water quality data.* Water resources research, 18(1), pp.107-121.

Larned S, Snelder T, Unwin M, McBride G, Verburg P, & McMillan H, 2015. *Analysis of Water Quality in New Zealand Lakes and Rivers.* Prepared for Ministry for the Environment. NIWA client Report CHC2015-033.

McBride, G.B., 2019. *Has water quality improved or been maintained? A quantitative assessment procedure*. Journal of environmental quality, 48(2), pp.412-420.

MfE, 2003: *Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*. Ministry for the Environment and Ministry of Health, Wellington.

National Environmental Monitoring Standards, 2019. *Water Quality. Part 3 of 4: Sampling, Measuring, Processing and Archiving of Discrete Lake Water Quality Data. Version 1.0.0.* https://www.nems.org.nz/documents/water-quality-part-3-lakes/

New Zealand Government, 2017. *National Policy Statement for Freshwater Management 2014 (as amended in 2017)*. Wellington, N.Z.

Schallenberg M, & van der Zon K, 2021. *Review of the Lake Trophic Level Index*. Prepared for the Regional Council Lakes Focus Group. Envirolink report 2068-HBRC257.

Snelder, T. & Fraser, C. 2019. *The LWP-Trends Library; v1901 December 2019*, LWP Ltd Report.

Taranaki Catchment Board, 1988. *Lake Rotorangi - monitoring a new hydro lake.* Taranaki Catchment Board, Stratford.

Taranaki Catchment Board, 1989. *Water right compliance monitoring programme Egmont Electric Power Board Patea Dam.* Taranaki Catchment Board, Stratford.

Taranaki Regional Council, 1990. *Egmont Electricity Lake Rotorangi 1989/90 Monitoring Report*. Taranaki Regional Council Technical Report 90-30.

Taranaki Regional Council, 1991. *Egmont Electricity Lake Rotorangi 1990/91 Monitoring Annual Report. Water Quality and Biological Programmes*. Taranaki Regional Council Technical Report 91-21.

Taranaki Regional Council, 1991a. *Egmont Electricity Patea Hydro Riverbed Monitoring Annual Report 1990/91*. Taranaki Regional Council Technical Report 91-39.

Taranaki Regional Council, 1992. *Egmont Electricity Ltd Lake Rotorangi 1991/92 Monitoring Annual Report. Water Quality and Biological Programmes*. Taranaki Technical Report 92-30.

Taranaki Regional Council, 1992a. *Egmont Electricity Patea Riverbed Monitoring Annual Report 1991/92.* Taranaki Regional Council Technical Report 92-39.

Taranaki Regional Council, 1993. *Egmont Electricity Ltd Lake Rotorangi 1992/93 Monitoring Annual Report Water Quality and Biological Programmes*. Taranaki Regional Council Technical Report 93-37.

Taranaki Regional Council, 1994. *Egmont Electricity Ltd Lake Rotorangi 1993/94 Monitoring Annual Report Water Quality and Biological Programmes*. Taranaki Regional Council Technical Report 94-41.

Taranaki Regional Council, 1995. *Egmont Electricity Ltd Lake Rotorangi 1994/95 Monitoring Annual Report Water Quality and Biological Programmes*. Taranaki Regional Council Technical Report 95-18.

Taranaki Regional Council, 1996. *Egmont Electricity Ltd Lake Rotorangi 1995/96 Monitoring Annual Report Water Quality and Biological Programmes*. Taranaki Regional Council Technical Report 96-57.

Taranaki Regional Council, 1996a. *State of the Environment – Taranaki Region 1996.* TRC publication.

Taranaki Regional Council, 1997. *Egmont Electricity Ltd Lake Rotorangi 1996/97 Monitoring Annual Report Water Quality and Biological Programmes*. Taranaki Regional Council Technical Report 97-78.

Taranaki Regional Council, 1998. *Powerco Ltd Lake Rotorangi 1997/98 Monitoring Annual Report Water Quality and Biological Programmes.* Taranaki Regional Council Technical Report 98-78.

Taranaki Regional Council, 1999. *Powerco Ltd and Taranaki Generation Ltd Lake Rotorangi 1998-1999 Monitoring Programme. Water Quality and Biological Programmes.* Taranaki Regional Council Technical Report 99-89.

Taranaki Regional Council, 2000. *Taranaki Generation Ltd Lake Rotorangi 1999-2000 Monitoring Programme. Water quality and biological programmes.* Taranaki Regional Council Technical Report 2000-90.

Taranaki Regional Council, 2001. *Taranaki Generation Ltd Lake Rotorangi 2000-2001 Monitoring Programme. Water quality and biological programmes*. Taranaki Regional Council Technical Report 2001-78.

Taranaki Regional Council, 2002. *Taranaki Generation Ltd Lake Rotorangi 2001-2002 Monitoring Programme. Water quality and biological programmes.* Taranaki Regional Council Technical Report 2002-36.

Taranaki Regional Council, 2003. *Taranaki Generation Ltd Lake Rotorangi 2002-2003 Monitoring Programme. Water quality and biological programmes.* Taranaki Regional Council Technical Report 2003-24.

Taranaki Regional Council, 2003a. *Taranaki – Our Place Our Future. Report on the state of the environment of the Taranaki region – 2003.* TRC publication.

Taranaki Regional Council, 2004: Taranaki Generation Ltd Lake Rotorangi 2003-2004 Monitoring Programme. Water quality and biological programmes. Taranaki Regional Council Technical Report 2004-69.

Taranaki Regional Council, 2005: Taranaki Generation Ltd Lake Rotorangi 2004-2005 Monitoring Programme. Water quality and biological programmes. Taranaki Regional Council Technical Report 2005-76.

Taranaki Regional Council, 2006. *Taranaki Generation Ltd Lake Rotorangi 2005-2006 Monitoring Programme. Water quality and biological programmes*. Taranaki Regional Council Technical Report 2006-76.

Taranaki Regional Council. 2006. *Trends in the quality of the surface waters of Taranaki.* TRC Internal Report.

Taranaki Regional Council, 2007. *TrustPower Ltd Lake Rotorangi 2006-2007 Monitoring Programme. Water quality and biological programmes*. Taranaki Regional Council Technical Report 2007-91.

Taranaki Regional Council, 2008. *TrustPower Ltd Lake Rotorangi 2007-2008 Monitoring Programme. Water quality and biological programmes.* Taranaki Regional Council Technical Report 2008-45.

Taranaki Regional Council, 2008a. *Recreational use of coast, rivers and lakes in Taranaki 2007-2008.* Taranaki Regional Council Report.

Taranaki Regional Council, 2009. *TrustPower Ltd Lake Rotorangi 2008-2009 Monitoring Programme. Water quality and biological programmes*. Taranaki Regional Council Technical Report 2009-50.

Taranaki Regional Council. 2009a. *Taranaki Where We Stand. State of the Environment Report 2009.* TRC publication.

Taranaki Regional Council, 2010. *TrustPower Ltd Lake Rotorangi 2009-2010 Monitoring Programme. Water quality and biological programmes*. Taranaki Regional Council Technical Report 2010-50.

Taranaki Regional Council, 2011. *TrustPower Ltd Lake Rotorangi 2010-2011 Monitoring Programme. Water quality and biological programmes.* Taranaki Regional Council Technical Report 2011-40.

Taranaki Regional Council, 2012. *State of the environment monitoring of Lake Rotorangi: water quality and biological programme Annual Report 2011-2012*. Taranaki Regional Council Technical Report 2012-08.

Taranaki Regional Council, 2013. *State of the environment monitoring of Lake Rotorangi: water quality and biological programme Annual Report 2012-2013*. Taranaki Regional Council Technical Report 2013-47.

Taranaki Regional Council, 2014. *State of the environment monitoring of Lake Rotorangi: water quality and biological programme Annual Report 2013-2014*. Taranaki Regional Council Technical Report 2014-22.

Taranaki Regional Council, 2015. *State of the environment monitoring of Lake Rotorangi: water quality and biological programme Annual Report 2014-2015*. Taranaki Regional Council Technical Report 2015-32.

Taranaki Regional Council. 2015a. *Taranaki – as one. State of the Environment Report 2015.* TRC publication.

Taranaki Regional Council, 2016. *State of the environment monitoring of Lake Rotorangi: water quality and biological programme Annual Report 2015-2016*. Taranaki Regional Council Technical Report 2016-82.

Taranaki Regional Council, 2018. *State of the Environment Monitoring of Lake Rotorangi: water quality and biological programme Annual Reports 2016-2018*. Taranaki Regional Council Technical Report 2018-90.

Taranaki Regional Council, 2020. *State of the Environment Monitoring of Lake Rotorangi water quality and biological programme Annual Report 2018-2019*. Taranaki Regional Council Technical Report 2019-97.

Appendix I

Trend analysis methodology

A number of changes to data analysis methodologies have been implemented in this report. A brief description of the current methods used is given below, while a discussion of how these differ from methods used in previous TRC SEM lake reports is given in Section 4.1 and Appendix VI of this report.

When assessing point (state) statistics, such as those used to construct the boxplots in this report, censored data has been handled using the NADA R package (vers. 1.6-1.1; Lopaka Lee, 2020). 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 boxplots are more robust than those used in previous reports, where summary statistics were biased by censored data being replaced with a value equal to half the censor limit. Even with this improved method of handling censored data, however, summary statistics (e.g. 25th percentile, median) that are less than the highest common censor limit, should not be directly interpreted.

In this report, trend analysis has been 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 previous TRC Lake SEM reports, 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. A note is included in the reported results when the median Sen-slope is affected by censored data. 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. In a small number of cases, trend assessment is not carried out due to insufficient unique data. This occurs when there are <5 non-censored data, or if there are 3 or less unique non-censored values.

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 4. A comparison between the results of the confidence grading system and the previous p-value based significance method is given in Appendix V.

Table 1 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%

It is noted that the trend analysis methods implemented above are constrained to identifying a monotonic (single direction) trend through any time-series. In many cases, however, environmental time-series data is not monotonic, with a change of conditions or individual events resulting in changes of behaviour at monitoring sites. To account for this, a Loess curve has been overlaid on trend-analysis plots to allow for a qualitative assessment of any non-monotonic trends, and further investigation into the possible cause of any change of behaviour. In addition, a comparison of long term (25 year) and short term (10 year) quantitative trends is undertaken.

In the case of parameters which 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 during the stratified period mean that combining the data from both stratified layers may mask any trends present. 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).

For the analysis of the lake as a whole, results taken at different sites, within the same layer of the water column and on the same day, are averaged to provide a single result. These average values are analysed as described above. This is consistent with the methodology used in Larned et al, 2015).

Appendix II

Physicochemical Monitoring Results 2019-2020

Physicochemical monitoring results collected at Lake Rotorangi on 17 October 2019

Parameter	Unit	L2					L3				
		Surface	Photic	Epilimnion	Hypolimnion	Near benthos	Surface	Photic	Epilimnion	Hypolimnion	Near benthos
Sample depth	m	0	1.6	5	25.6	N/S	0	5.6	5	32.95	N/S
Temperature	° C	14.2	-	14.2	9.7	N/S	14.1	-	13.7	9.55	N/S
Black disc transparency	m	0.475	-	-	-	N/S	1.505	-	-	-	N/S
Secchi disc transparency	m	0.655	-	-	-	N/S	2.255	-	-	-	N/S
Dissolved oxygen	g/m^3	8.1	-	7.9	4.9	N/S	10.0	-	9.7	0.35	N/S
pH	pH units	7.3	-	7.2	7.1	N/S	7.7	-	7.6	7.0	N/S
Conductivity	µS/cm	94	-	94	126	N/S	119	-	118	121	N/S
Turbidity	FNU	12.6	-	12.6	3.2	N/S	2.3	-	2.7	1.71	N/S
Suspended solids	g/m^3	8	-	9	< 3	N/S	< 3	-	< 3	< 3	N/S
E. coli	MPN/100mL	365	-	-	-	N/S	11	-	-	-	N/S
Dissolved reactive phosphorus	g/m^3 P	-	-	0.0100	0.0042	N/S	-	-	0.0023	0.0031	N/S
Total phosphorus	g/m^3 P	-	-	0.066	0.016	N/S	-	-	0.016	0.012	N/S
Ammoniacal nitrogen	g/m^3 N	-	-	0.138	< 0.005	N/S	-	-	0.008	< 0.005	N/S
Nitrite nitrogen	g/m^3 N	-	-	0.0150	0.0012	N/S	-	-	0.0060	< 0.0010	N/S
Nitrate nitrogen	g/m^3 N	-	-	0.48	0.75	N/S	-	-	0.48	0.57	N/S
Nitrate and nitrite nitrogen	g/m^3 N	-	-	0.50	0.75	N/S	-	-	0.49	0.57	N/S
Total Kjeldahl nitrogen	g/m^3 N	-	-	0.47	0.16	N/S	-	-	0.23	0.14	N/S
Total nitrogen	g/m^3 N	-	-	0.96	0.91	N/S	-	-	0.72	0.71	N/S
Chlorophyll-a	g/m^3	-	0.0007	-	-	N/S	-	0.0021	-	-	N/S

N/S = not sampled

Physicochemical monitoring results collected at Lake Rotorangi on 19 February 2020

Parameter	Unit	L2					L3				
		Surface	Photic	Epilimnion	Hypolimnion	Near benthos	Surface	Photic	Epilimnion	Hypolimnion	Near benthos
Sample depth	m	0	11	4.95	27.0	35.0	0	8.3	4.95	33.5	50
Temperature	° C	22.8	-	23.0	10.0	9.7	23.3	-	23.2	9.7	9.5
Black disc transparency	m	2.84	-	-	-	-	2.075	-	-	-	-
Secchi disc transparency	m	4.40	-	-	-	-	3.335	-	-	-	-
Dissolved oxygen	g/m^3	8.6	-	8.47	0	0	8.71	-	8.42	0	0
pH	pH units	7.9	-	7.7	6.9	7.0	7.8	-	7.7	6.9	6.9
Conductivity	μS/cm	15.2	-	15.3	12.9	-	11.8	-	11.7	12.5	-
Turbidity	FNU	0.60	-	0.60	0.93	43	0.63	-	0.81	0.69	4.9
Suspended solids	g/m^3	< 3	-	< 3	< 3	-	< 3	-	< 3	< 3	-
E. coli	MPN/100mL	1	-	-	-	-	3	-	-	-	-
Dissolved reactive phosphorus	g/m^3 P	-	-	0.0029	0.0052	0.0042	-	-	0.0016	0.0044	0.0026
Total phosphorus	g/m^3 P	-	-	0.015	0.013	0.073	-	-	0.008	0.008	0.013
Ammoniacal nitrogen	g/m^3 N	-	-	0.012	0.052	0.163	-	-	0.007	< 0.005	0.050
Nitrite nitrogen	g/m^3 N	-	-	0.0017	0.0091	-	-	-	0.0027	< 0.0010	-
Nitrate nitrogen	g/m^3 N	-	-	0.037	0.51	-	-	-	0.165	0.51	-
Nitrate and nitrite nitrogen	g/m^3 N	-	-	0.038	0.52	0.40	-	-	0.168	0.51	0.37
Total Kjeldahl nitrogen	g/m^3 N	-	-	0.12	0.16	-	-	-	0.20	0.12	-
Total nitrogen	g/m^3 N	-	-	0.15	0.68	-	-	-	0.37	0.64	-
Chlorophyll-a	g/m^3	-	0.0040	-	-	-	-	0.0019	-	-	-

Physicochemical monitoring results collected at Lake Rotorangi on 19 March 2020

Parameter	Unit	L2					L3				
		Surface	Photic	Epilimnion	Hypolimnion	Near benthos	Surface	Photic	Epilimnion	Hypolimnion	Near benthos
Sample depth	m	0	7.8	5.4	37	48	0	6.9	6.9	28	36
Temperature	° C	19.4	-	19.5	9.6	9.5	19.7	-	19.4	9.9	9.7
Black disc transparency	m	2.39	-	-	-	-	2.14	-	-	-	-
Secchi disc transparency	m	3.95	-	-	-	-	2.76	-	-	-	-
Dissolved oxygen	g/m^3	7.86	-	7.82	-0.12	-0.17	7.35	-	5.40	-1.0	-0.15
pH	pH units	7.4	-	7.5	7.0	7.2	7.4	-	7.3	7.3	7.3
Conductivity	µS/cm	13.9	-	13.8	12.4	-	15.7	-	15.6	13.5	-
Turbidity	FNU	0.82	-	0.96	0.63	3.4	1.00	-	1.35	3.6	9.8
Suspended solids	g/m^3	< 3	-	< 3	< 3	-	< 3	-	< 3	< 3	-
E. coli	MPN/100mL	2	-	-	-	-	2	-	-	-	-
Dissolved reactive phosphorus	g/m^3 P	-	-	0.0011	0.0023	0.0026	-	-	0.0022	0.0033	0.0024
Total phosphorus	g/m^3 P	-	-	0.013	0.005	0.009	-	-	0.022	0.014	0.008
Ammoniacal nitrogen	g/m^3 N	-	-	< 0.005	< 0.005	0.039	-	-	0.033	0.102	0.177
Nitrite nitrogen	g/m^3 N	-	-	0.0017	< 0.0010	-	-	-	0.0053	< 0.0010	-
Nitrate nitrogen	g/m^3 N	-	-	0.105	0.59	-	-	-	0.141	0.42	-
Nitrate and nitrite nitrogen	g/m^3 N	-	-	0.107	0.59	0.33	-	-	0.146	0.42	0.37
Total Kjeldahl nitrogen	g/m^3 N	-	-	0.14	0.13	-	-	-	0.27	0.21	-
Total nitrogen	g/m^3 N	-	-	0.24	0.72	-	-	-	0.41	0.64	-
Chlorophyll-a	g/m^3	-	0.0038	-	-	-	-	0.0039	-	-	-

Physicochemical monitoring results collected at Lake Rotorangi on 23 June 2020

Parameter	Unit	L2					L3				
		Surface	Photic	Epilimnion	Hypolimnion	Near benthos	Surface	Photic	Epilimnion	Hypolimnion	Near benthos
Sample depth	m	0	2.3	2.3	35	N/S	0	5.6	5.6	34	N/S
Temperature	° C	11.2	-	11.4	9.9	N/S	11.4	-	11.3	9.8	N/S
Black disc transparency	m	0.78	-	-	-	N/S	1.64	-	-	-	N/S
Secchi disc transparency	m	0.93	-	-	-	N/S	2.25	-	-	-	N/S
Dissolved oxygen	g/m^3	9.82	-	9.65	0.11	N/S	8.25	-	7.80	0	N/S
pH	pH units	7.4	-	7.5	7.0	N/S	7.0	-	7.4	6.9	N/S
Conductivity	µS/cm	11.4	-	11.5	14.4	N/S	12.0	-	12.0	13.0	N/S
Turbidity	FNU	6.2	-	6.6	6.3	N/S	2.2	-	2.2	1.34	N/S
Suspended solids	g/m^3	5	-	5	3	N/S	< 3	-	< 3	< 3	N/S
E. coli	MPN/100mL	384	-	-	-	N/S	4	-	-	-	N/S
Dissolved reactive phosphorus	g/m^3 P	-	-	0.0075	0.0034	N/S	-	-	0.0042	0.0031	N/S
Total phosphorus	g/m^3 P	-	-	0.032	0.014	N/S	-	-	0.018	0.012	N/S
Ammoniacal nitrogen	g/m^3 N	-	-	0.028	0.23	N/S	-	-	0.007	0.022	N/S
Nitrite nitrogen	g/m^3 N	-	-	0.0074	0.0166	N/S	-	-	0.0057	< 0.0010	N/S
Nitrate nitrogen	g/m^3 N	-	-	0.57	0.183	N/S	-	-	0.58	0.35	N/S
Nitrate and nitrite nitrogen	g/m^3 N	-	-	0.57	0.20	N/S	-	-	0.58	0.35	N/S
Total Kjeldahl nitrogen	g/m^3 N	-	-	0.20	0.38	N/S	-	-	0.21	0.15	N/S
Total nitrogen	g/m^3 N	-	-	0.77	0.58	N/S	-	-	0.79	0.50	N/S
Chlorophyll-a	g/m^3	-	< 0.0002	-	-	N/S	-	< 0.0002	-	-	N/S

N/S = not sampled

Appendix III

Trophic Level Index

Trophic level and state, with trophic level components and annual average values used in to calculate the trophic level of Lake Rotorangi as a whole

Monitoring Year	Chlorophyll-a (mg m^{-3})	Secchi Depth (m)	Total Nitrogen (mg m^{-3})	Total Phosphorus (mg m^{-3})	TLc	TLs	TLn	TLp	TLI	Trophic State
1996	1.93	3.46	538.75	20.75	2.95	4.06	4.61	4.06	3.92	Mesotrophic
1997	2.56	3.03	559.00	16.20	3.26	4.22	4.66	3.75	3.97	Mesotrophic
1998	2.54	2.81	623.00	17.50	3.25	4.31	4.80	3.85	4.05	Eutrophic
1999	2.68	3.38	751.00	43.70	3.31	4.09	5.05	5.01	4.36	Eutrophic
2000	3.19	3.71	641.00	15.60	3.50	3.97	4.84	3.70	4.00	Eutrophic
2001	2.24	3.22	989.00	18.50	3.11	4.14	5.41	3.92	4.14	Eutrophic
2002	2.95	2.73	836.00	27.10	3.41	4.35	5.19	4.40	4.34	Eutrophic
2003	2.97	3.52	586.25	20.88	3.42	4.03	4.72	4.07	4.06	Eutrophic
2004	3.80	0.71	914.00	61.20	3.69	5.92	5.30	5.44	5.09	Supertrophic
2005	2.59	2.94	601.00	20.20	3.27	4.26	4.75	4.03	4.08	Eutrophic
2006	3.49	2.53	624.00	26.20	3.60	4.44	4.80	4.36	4.30	Eutrophic
2007	3.08	3.23	493.33	13.50	3.46	4.14	4.50	3.52	3.90	Mesotrophic
2008	1.75	3.34	643.00	20.40	2.84	4.10	4.84	4.04	3.96	Mesotrophic
2009	3.84	2.95	586.00	16.80	3.70	4.25	4.72	3.80	4.12	Eutrophic
2010	3.67	2.40	640.00	23.30	3.66	4.50	4.84	4.21	4.30	Eutrophic
2011	4.31	2.65	732.00	35.00	3.83	4.38	5.01	4.73	4.49	Eutrophic
2012	3.32	2.99	580.00	34.00	3.54	4.24	4.71	4.69	4.29	Eutrophic
2013	4.21	3.05	558.00	26.80	3.81	4.21	4.66	4.39	4.27	Eutrophic
2014	6.12	3.04	475.00	28.50	4.22	4.22	4.45	4.47	4.34	Eutrophic
2015	3.92	2.76	900.00	186.20	3.73	4.33	5.28	6.85	5.05	Supertrophic
2016	2.87	2.88	530.00	23.12	3.38	4.28	4.59	4.20	4.11	Eutrophic
2017	3.98	2.54	614.00	32.70	3.74	4.43	4.78	4.64	4.40	Eutrophic
2018	6.08	2.07	707.00	42.40	4.21	4.68	4.97	4.97	4.71	Eutrophic
2019	2.55	3.86	552.00	19.50	3.25	3.92	4.64	3.98	3.95	Mesotrophic
2020	2.10	2.57	549.00	21.60	3.04	4.42	4.64	4.11	4.04	Eutrophic

Trophic level and state, with trophic level components and annual average values used in to calculate the trophic level at site L2 in Lake Rotorangi

Monitoring Year	Chlorophyll-a (mg m^{-3})	Secchi Depth (m)	Total Nitrogen (mg m^{-3})	Total Phosphorus (mg m^{-3})	TLc	TLs	TLn	TLp	TLI	Trophic State
1996	2.50	3.05	575.00	24.50	3.23	4.21	4.70	4.27	4.10	Eutrophic
1997	2.28	2.36	558.00	21.20	3.13	4.52	4.66	4.09	4.10	Eutrophic
1998	2.15	2.36	642.00	21.00	3.06	4.52	4.84	4.08	4.13	Eutrophic
1999	2.53	3.29	690.00	37.75	3.25	4.12	4.93	4.82	4.28	Eutrophic
2000	4.35	3.52	676.00	18.20	3.84	4.03	4.91	3.90	4.17	Eutrophic
2001	2.72	3.34	1010.00	16.00	3.33	4.10	5.43	3.73	4.15	Eutrophic
2002	2.15	2.50	894.00	32.80	3.06	4.45	5.27	4.64	4.36	Eutrophic
2003	2.92	3.20	674.00	24.20	3.40	4.15	4.90	4.26	4.18	Eutrophic
2004	3.18	0.83	981.43	102.29	3.49	5.74	5.40	6.09	5.18	Supertrophic
2005	2.42	2.59	628.00	24.80	3.20	4.41	4.81	4.29	4.18	Eutrophic
2006	3.90	2.04	784.00	32.60	3.72	4.70	5.10	4.64	4.54	Eutrophic
2007	3.90	2.88	500.00	13.33	3.72	4.28	4.51	3.50	4.00	Eutrophic
2008	1.95	2.94	718.33	23.67	2.96	4.26	4.99	4.23	4.11	Eutrophic
2009	3.85	3.24	578.00	19.80	3.71	4.14	4.70	4.00	4.14	Eutrophic
2010	3.75	2.00	678.00	27.40	3.68	4.72	4.91	4.42	4.43	Eutrophic
2011	4.65	2.56	808.00	43.40	3.92	4.42	5.14	5.00	4.62	Eutrophic
2012	3.20	2.23	628.00	46.40	3.50	4.59	4.81	5.08	4.50	Eutrophic
2013	4.00	2.88	580.00	34.00	3.75	4.28	4.71	4.69	4.36	Eutrophic
2014	3.33	3.00	453.33	26.67	3.55	4.23	4.39	4.38	4.14	Eutrophic
2015	3.98	2.56	854.00	159.60	3.74	4.43	5.21	6.65	5.01	Supertrophic
2016	2.80	2.76	644.00	27.60	3.36	4.33	4.84	4.43	4.24	Eutrophic
2017	4.32	2.27	638.00	42.60	3.84	4.57	4.83	4.98	4.55	Eutrophic
2018	5.82	1.60	780.00	63.40	4.16	4.98	5.10	5.48	4.93	Eutrophic
2019	2.78	3.28	532.00	25.40	3.35	4.12	4.59	4.32	4.10	Eutrophic
2020	2.20	2.19	574.00	29.80	3.09	4.61	4.69	4.52	4.23	Eutrophic

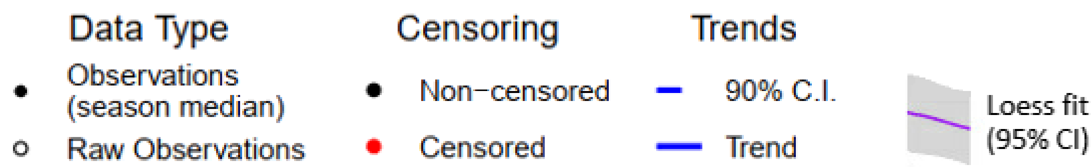
Trophic level and state, with trophic level components and annual average values used in to calculate the trophic level at site L3 in Lake Rotorangi

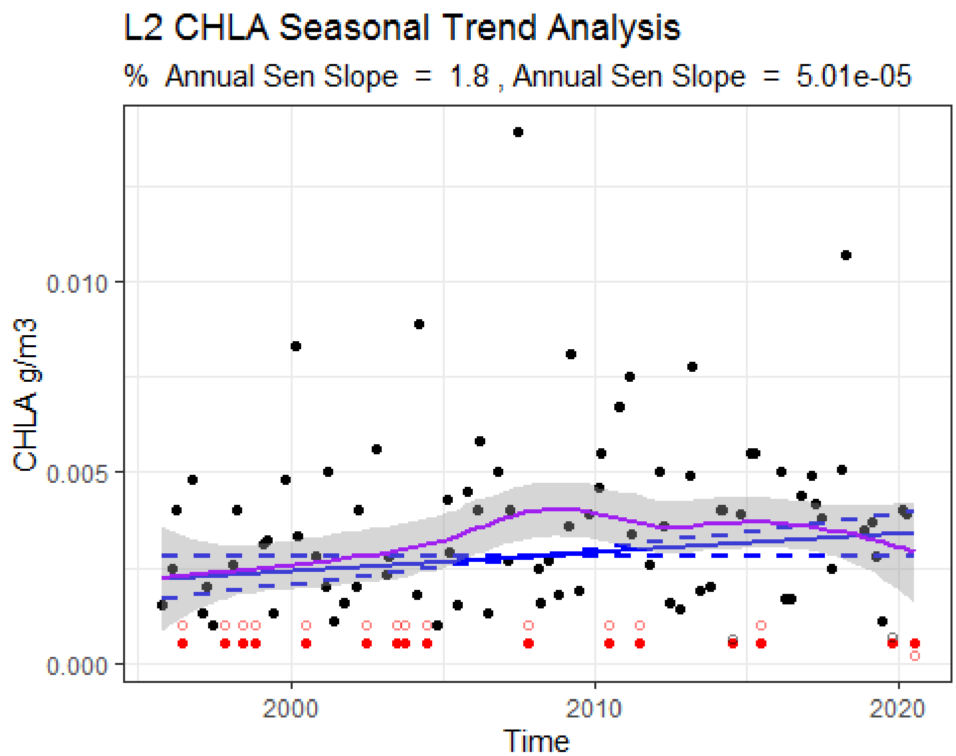
Monitoring Year	Chlorophyll-a (mg m^{-3})	Secchi Depth (m)	Total Nitrogen (mg m^{-3})	Total Phosphorus (mg m^{-3})	TLc	TLs	TLn	TLp	TLI	Trophic State
1996	1.37	3.87	502.50	17.00	2.56	3.92	4.52	3.81	3.70	Mesotrophic
1997	2.85	3.70	560.00	11.20	3.38	3.97	4.66	3.28	3.82	Mesotrophic
1998	2.92	3.26	604.00	14.00	3.40	4.13	4.76	3.56	3.97	Mesotrophic
1999	2.38	2.66	791.67	47.67	3.17	4.38	5.11	5.12	4.45	Eutrophic
2000	2.02	3.90	606.00	13.00	3.00	3.91	4.77	3.47	3.79	Mesotrophic
2001	1.75	3.10	968.00	21.00	2.84	4.19	5.38	4.08	4.12	Eutrophic
2002	3.75	2.96	778.00	21.40	3.68	4.25	5.09	4.10	4.28	Eutrophic
2003	3.02	3.85	555.00	23.00	3.44	3.92	4.65	4.19	4.05	Eutrophic
2004	4.42	0.59	840.00	50.80	3.86	6.13	5.19	5.20	5.10	Supertrophic
2005	2.75	3.28	574.00	15.60	3.34	4.12	4.69	3.70	3.96	Mesotrophic
2006	3.08	3.03	464.00	19.80	3.46	4.22	4.42	4.00	4.02	Eutrophic
2007	2.27	3.58	486.67	13.67	3.12	4.01	4.48	3.53	3.79	Mesotrophic
2008	1.55	3.75	634.00	17.80	2.70	3.96	4.82	3.87	3.84	Mesotrophic
2009	3.83	2.66	594.00	13.80	3.70	4.38	4.74	3.55	4.09	Eutrophic
2010	3.60	2.80	602.00	19.20	3.63	4.32	4.76	3.97	4.17	Eutrophic
2011	3.98	2.73	656.00	26.60	3.74	4.34	4.87	4.38	4.33	Eutrophic
2012	3.23	3.33	540.00	22.75	3.51	4.10	4.61	4.18	4.10	Eutrophic
2013	4.42	3.22	536.00	19.60	3.86	4.14	4.60	3.99	4.15	Eutrophic
2014	8.90	3.07	496.67	30.33	4.63	4.20	4.51	4.55	4.47	Eutrophic
2015	3.88	2.96	946.00	212.80	3.71	4.25	5.35	7.02	5.08	Supertrophic
2016	2.93	3.01	502.50	21.00	3.41	4.23	4.52	4.08	4.06	Eutrophic
2017	3.62	2.81	590.00	22.80	3.64	4.31	4.73	4.18	4.22	Eutrophic
2018	6.32	2.54	634.00	21.40	4.25	4.44	4.82	4.10	4.40	Eutrophic
2019	2.33	4.45	572.00	13.60	3.15	3.74	4.69	3.53	3.78	Mesotrophic
2020	2.00	2.95	524.00	13.40	2.98	4.25	4.58	3.51	3.83	Mesotrophic

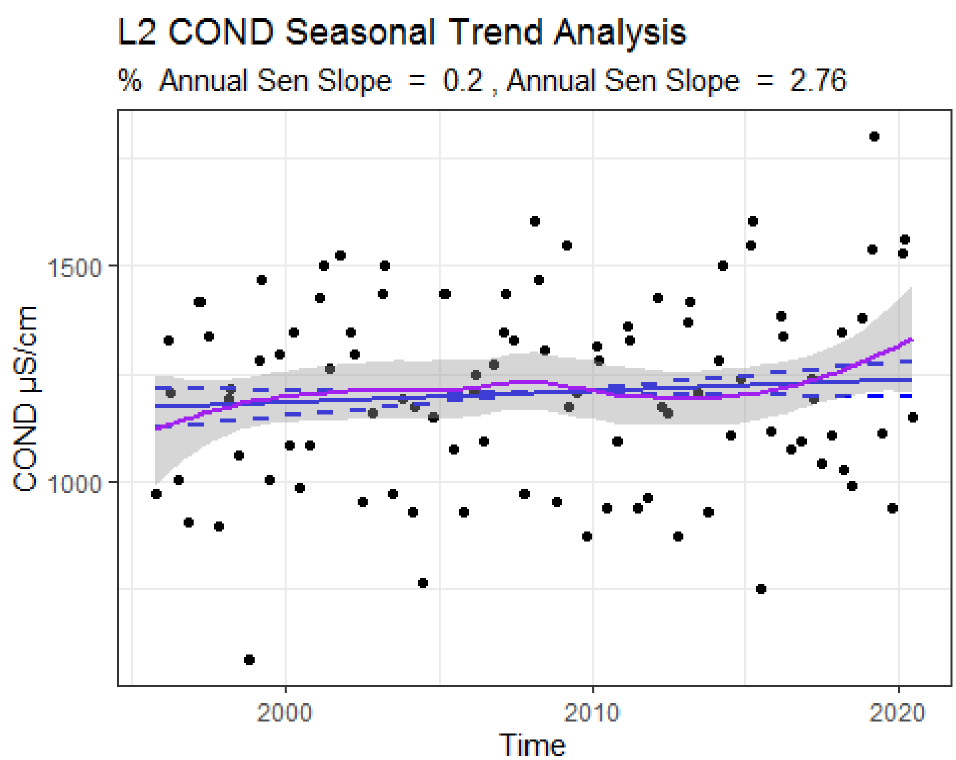
Appendix IV

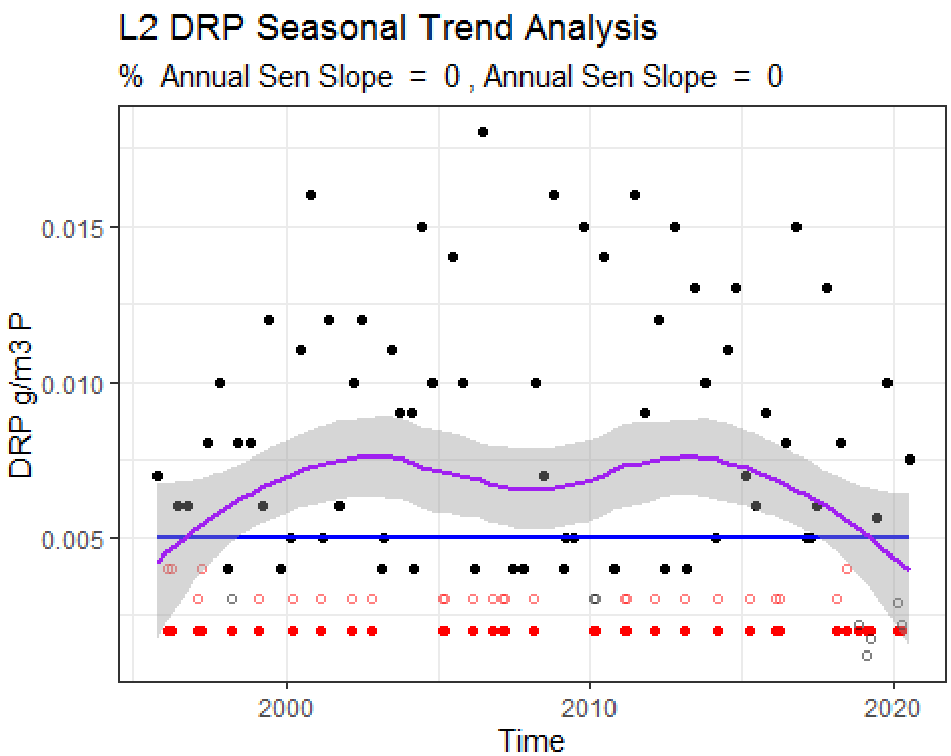
Trend plots for the period 1996-2020

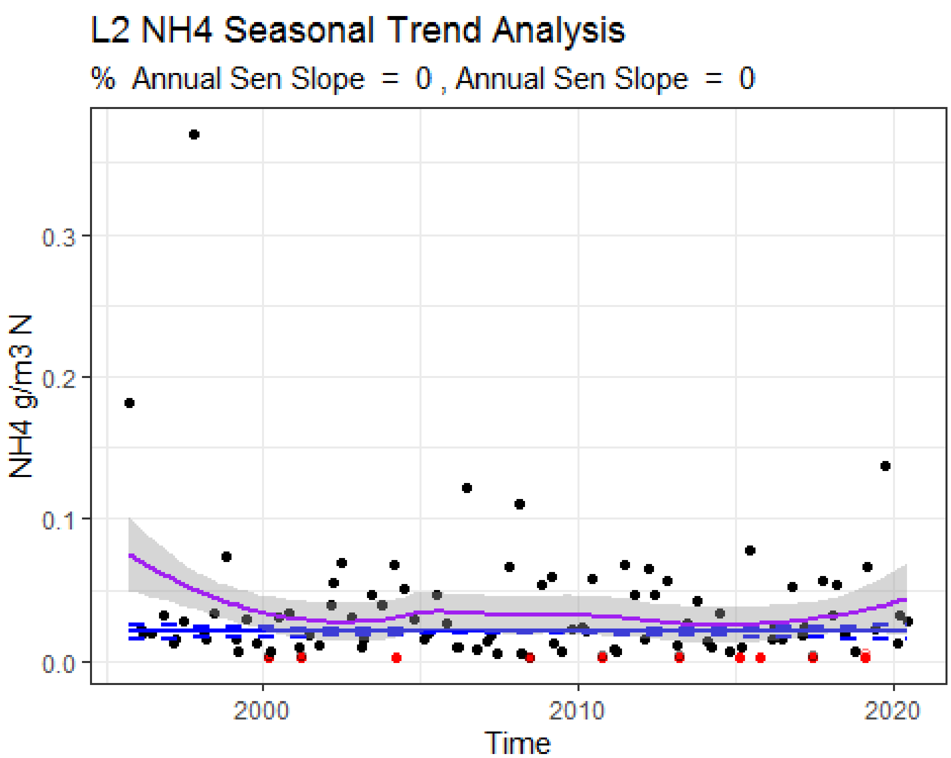
Legend for all trend plots:

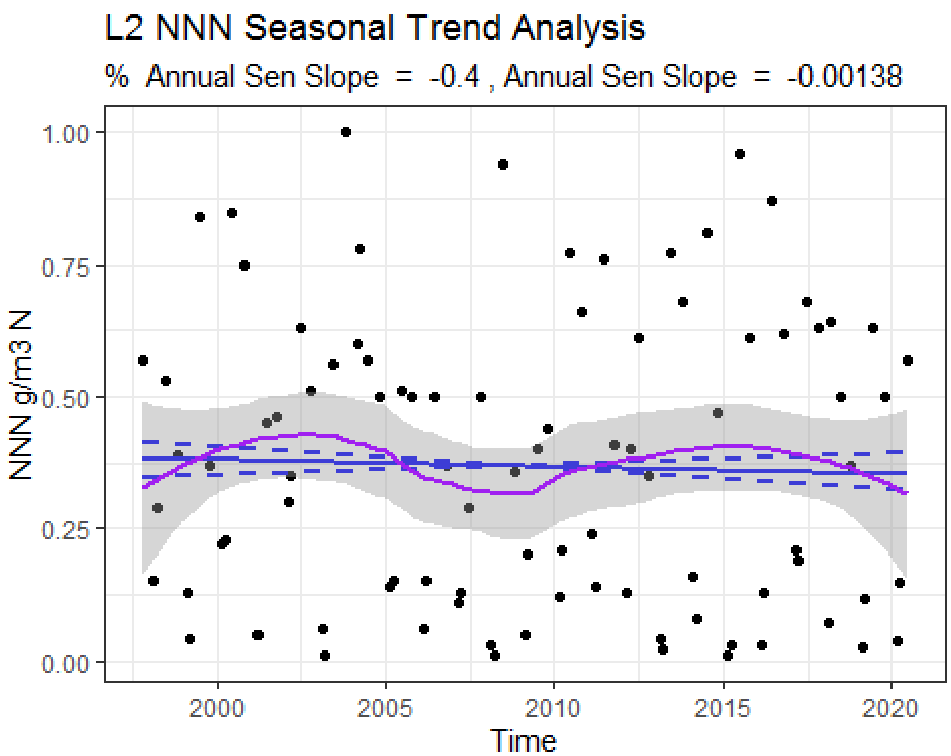


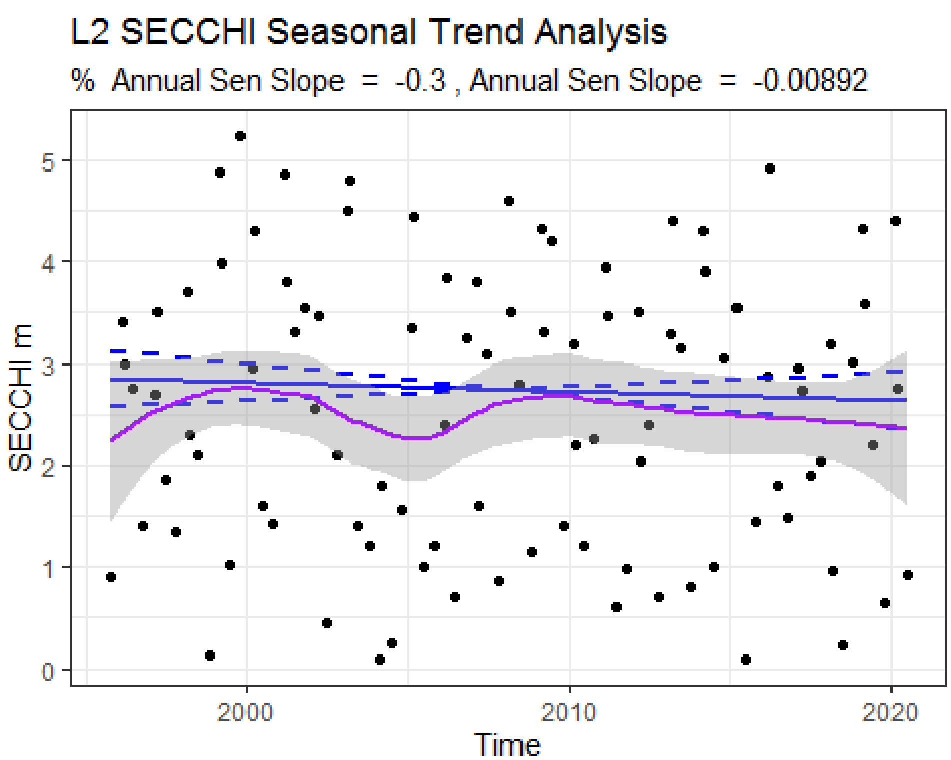

L2 CHLA Seasonal Trend Analysis
% Annual Sen Slope = 1.8 , Annual Sen Slope = 5.01e-05
CHLA g/m3
0.010
0.005
0.000
2000
2010
2020
Time


L2 COND Seasonal Trend Analysis
% Annual Sen Slope = 0.2 , Annual Sen Slope = 2.76
COND µS/cm
1500
1000
2000
2010
2020
Time


L2 DRP Seasonal Trend Analysis
% Annual Sen Slope = 0 , Annual Sen Slope = 0
DRP g/m3 P
0.015
0.010
0.005
2000
2010
2020
Time

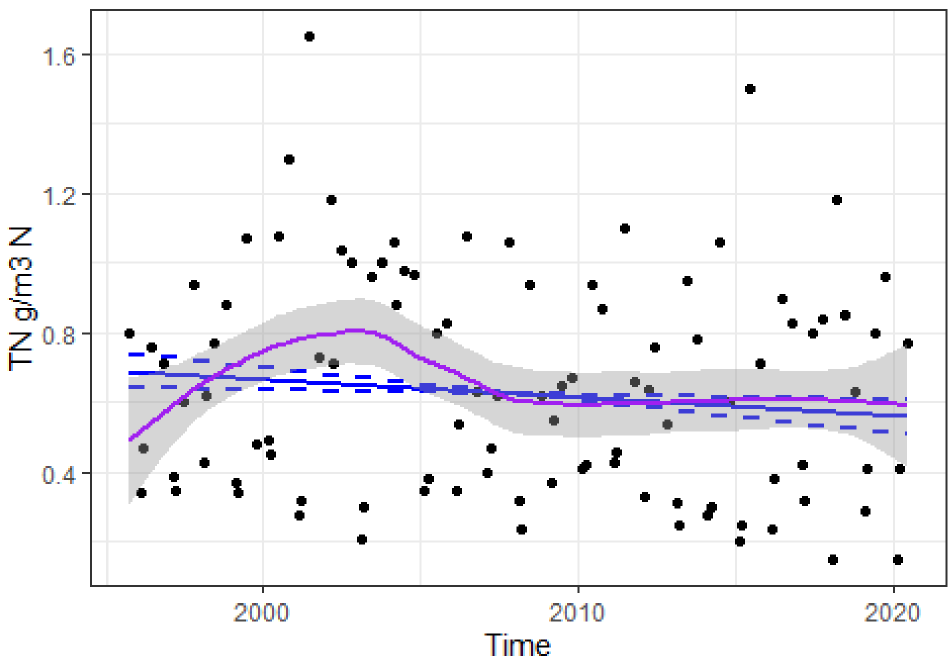

L2 NH4 Seasonal Trend Analysis
% Annual Sen Slope = 0 , Annual Sen Slope = 0
NH4 g/m3 N
0.3
0.2
0.1
0.0
2000
2010
2020
Time


L2 NNN Seasonal Trend Analysis
% Annual Sen Slope = -0.4 , Annual Sen Slope = -0.00138
NNN g/m3 N
1.00
0.75
0.50
0.25
0.00
2000
2005
2010
2015
2020
Time


L2 SECCHI Seasonal Trend Analysis
% Annual Sen Slope = -0.3 , Annual Sen Slope = -0.00892
SECCHI m
5
4
3
2
1
0
2000
2010
2020
Time

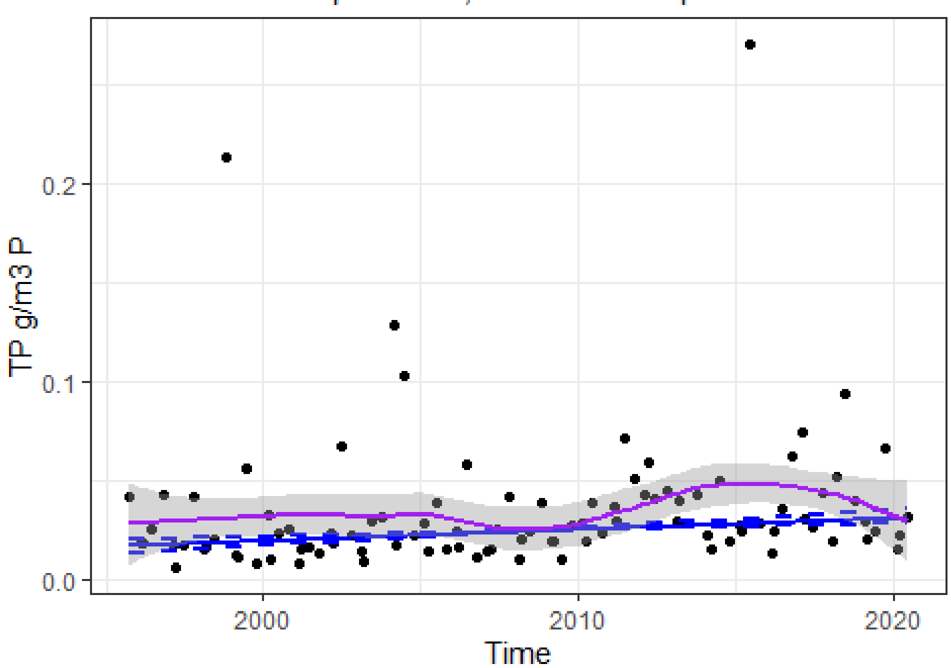
L2 TN Seasonal Trend Analysis

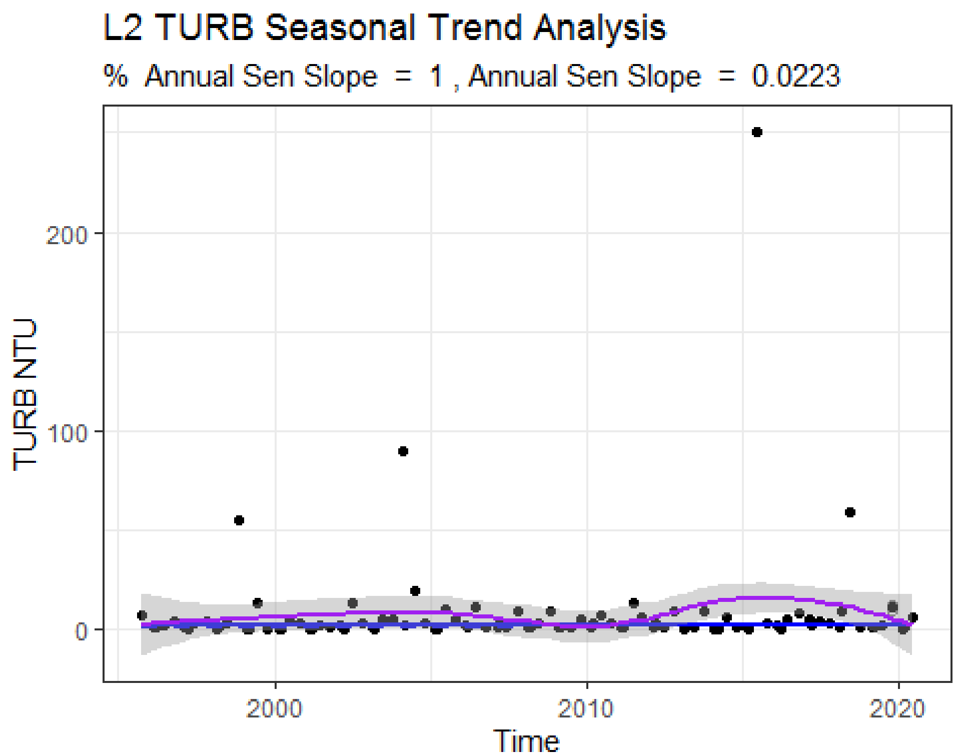
% Annual Sen Slope = -0.8 , Annual Sen Slope = -0.005



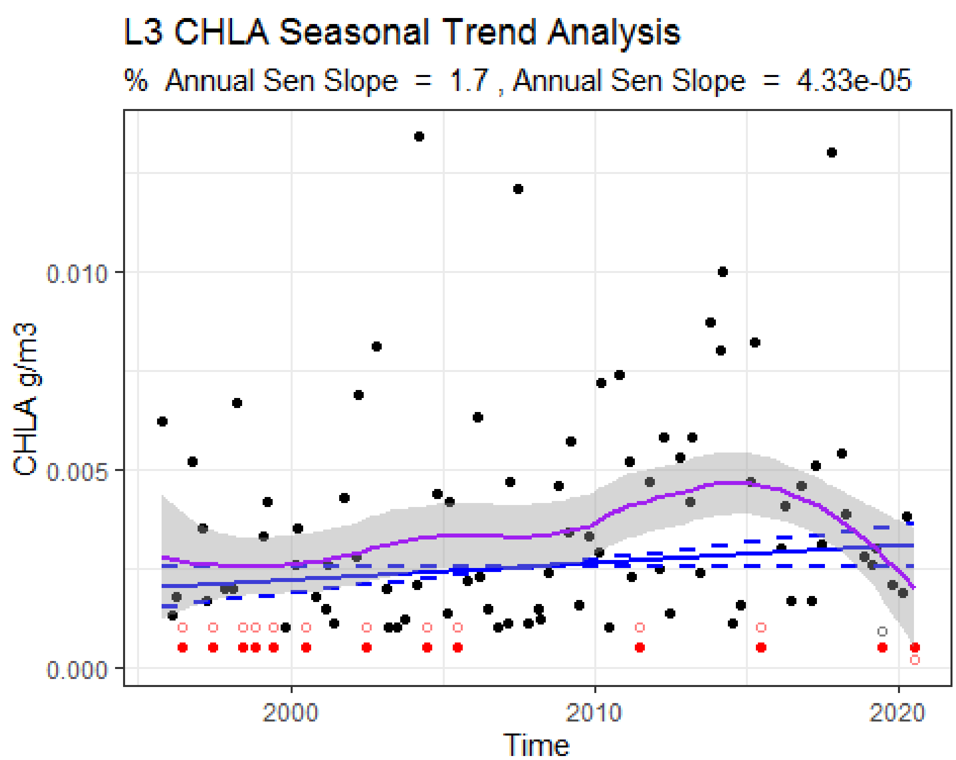
L2 TP Seasonal Trend Analysis

% Annual Sen Slope = 2.3 , Annual Sen Slope = 0.000566

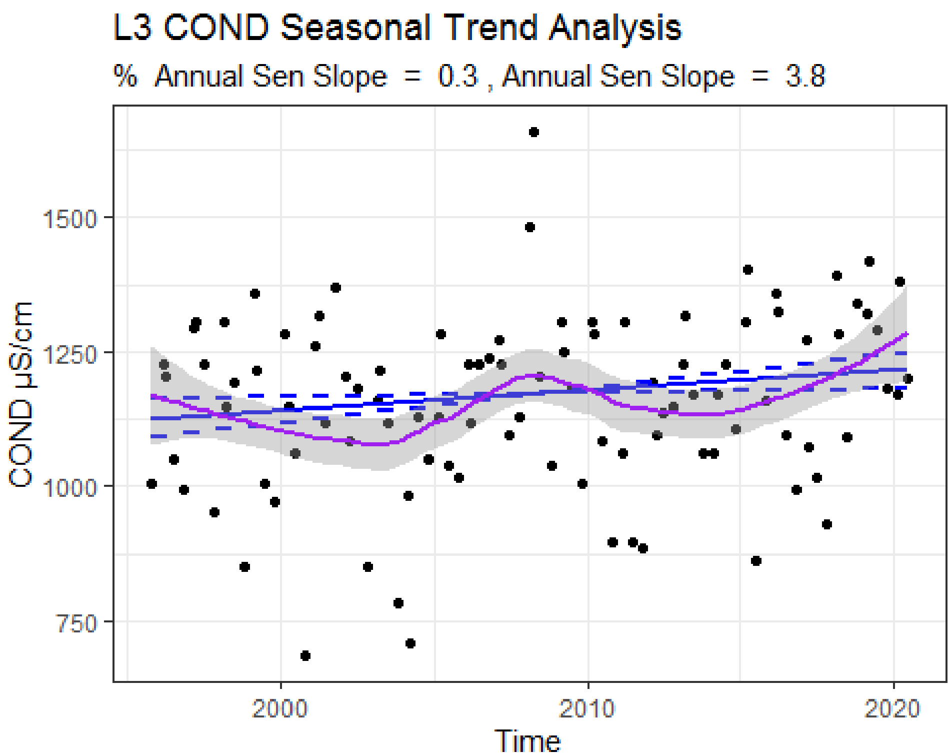




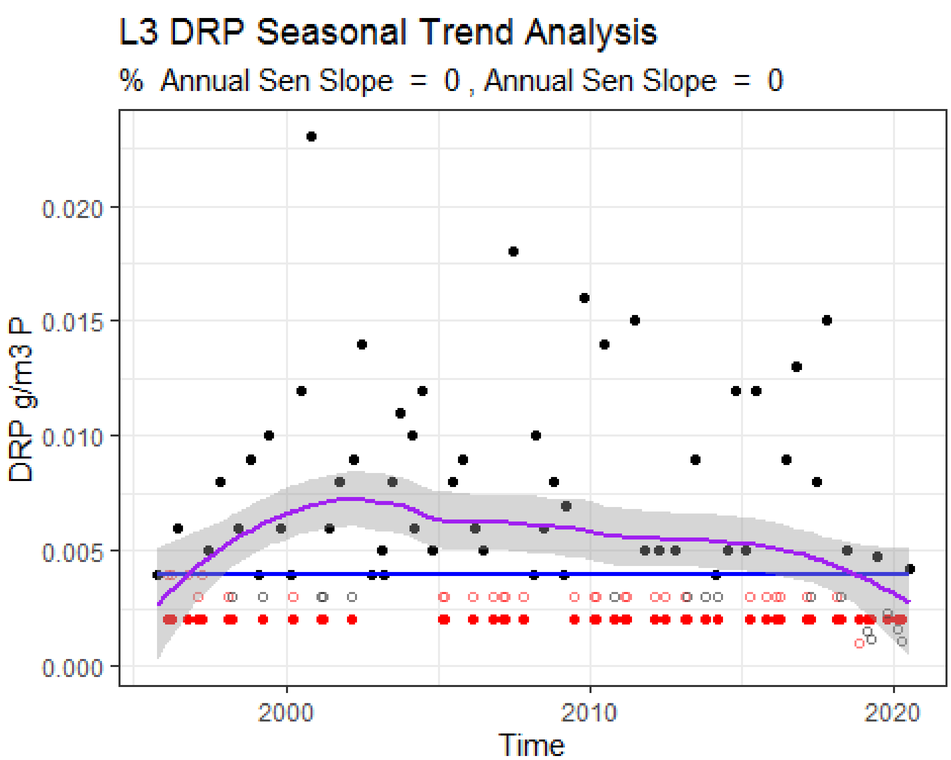
L2 TURB Seasonal Trend Analysis
% Annual Sen Slope = 1 , Annual Sen Slope = 0.0223
TURB NTU
200
100
0
2000
2010
2020
Time



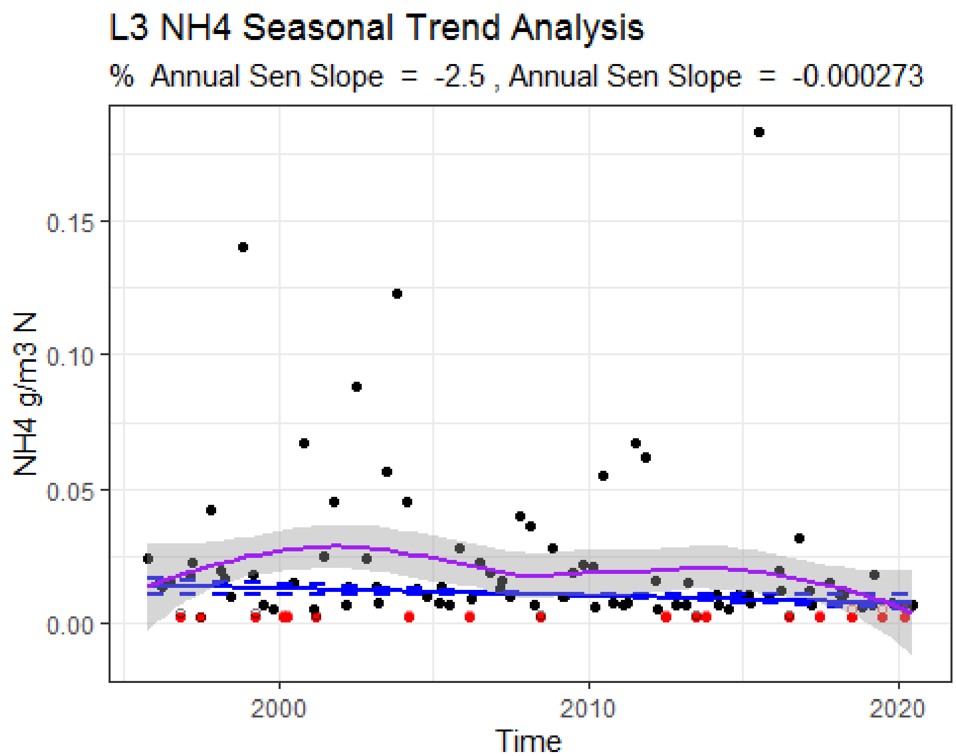
L3 CHLA Seasonal Trend Analysis
% Annual Sen Slope = 1.7 , Annual Sen Slope = 4.33e-05
CHLA g/m3
0.010
0.005
0.000
2000
2010
2020
Time

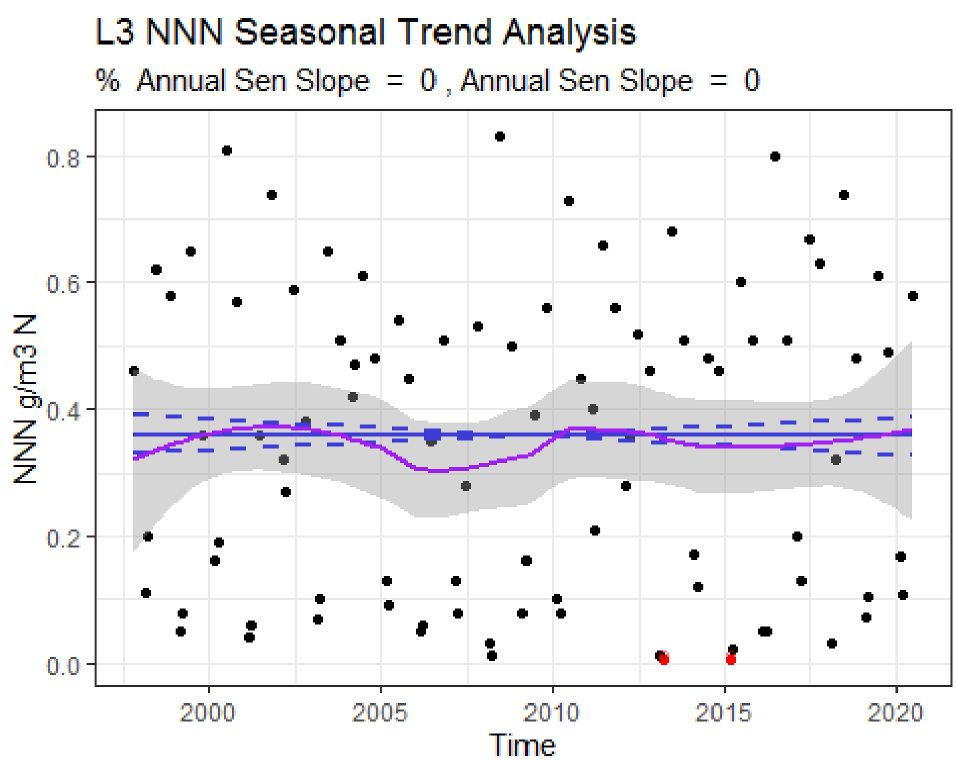


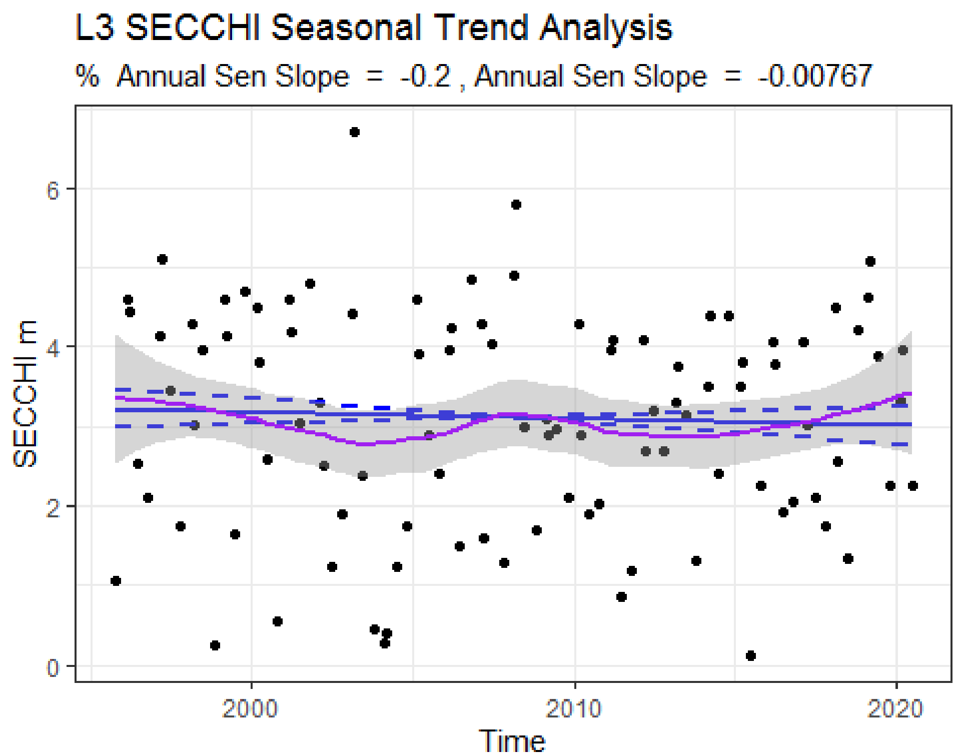
L3 COND Seasonal Trend Analysis
% Annual Sen Slope = 0.3 , Annual Sen Slope = 3.8
COND µS/cm
1500
1250
1000
750
2000
2010
2020
Time

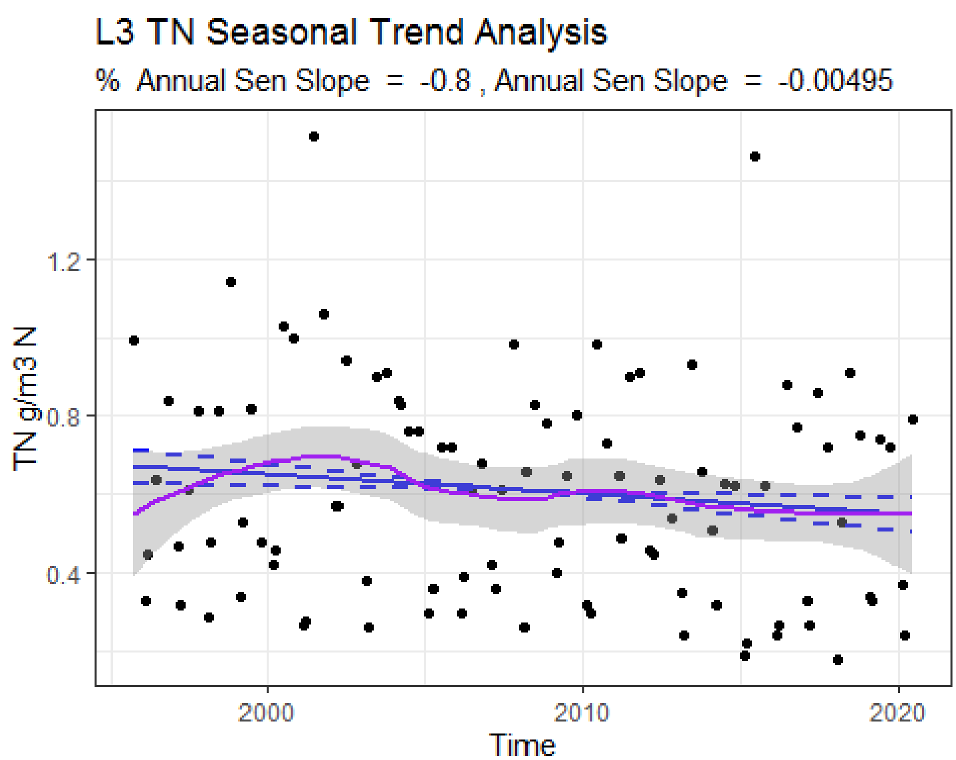


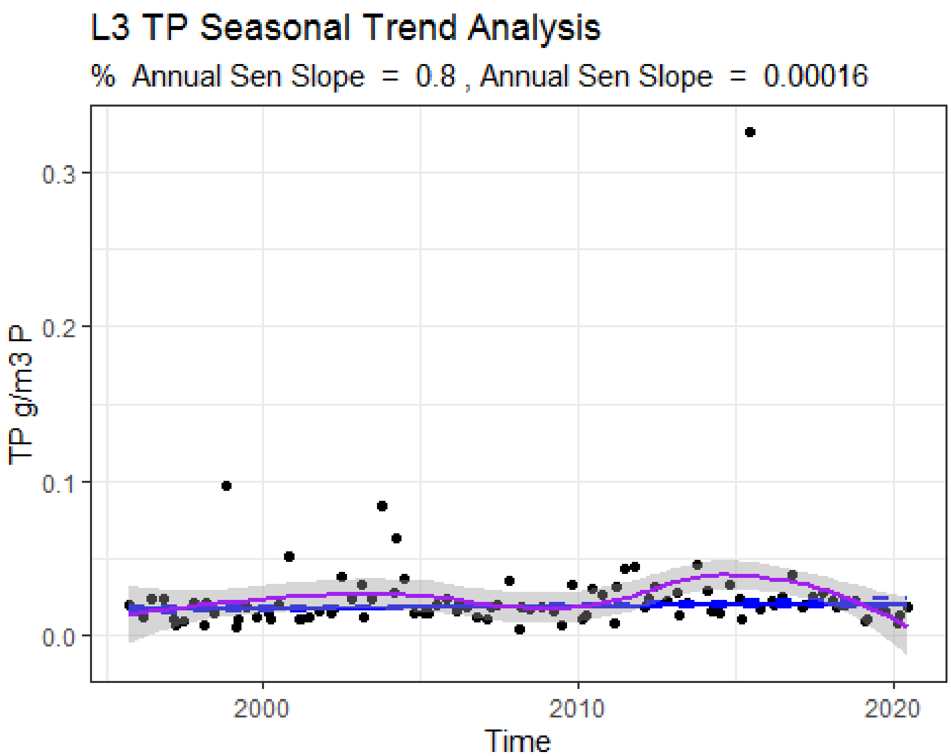
L3 DRP Seasonal Trend Analysis
% Annual Sen Slope = 0 , Annual Sen Slope = 0
DRP g/m3 P
0.020
0.015
0.010
0.005
0.000
2000
2010
2020
Time


L3 NH4 Seasonal Trend Analysis
% Annual Sen Slope = -2.5 , Annual Sen Slope = -0.000273
NH4 g/m3 N
0.00
0.05
0.10
0.15
2000
2010
2020
Time

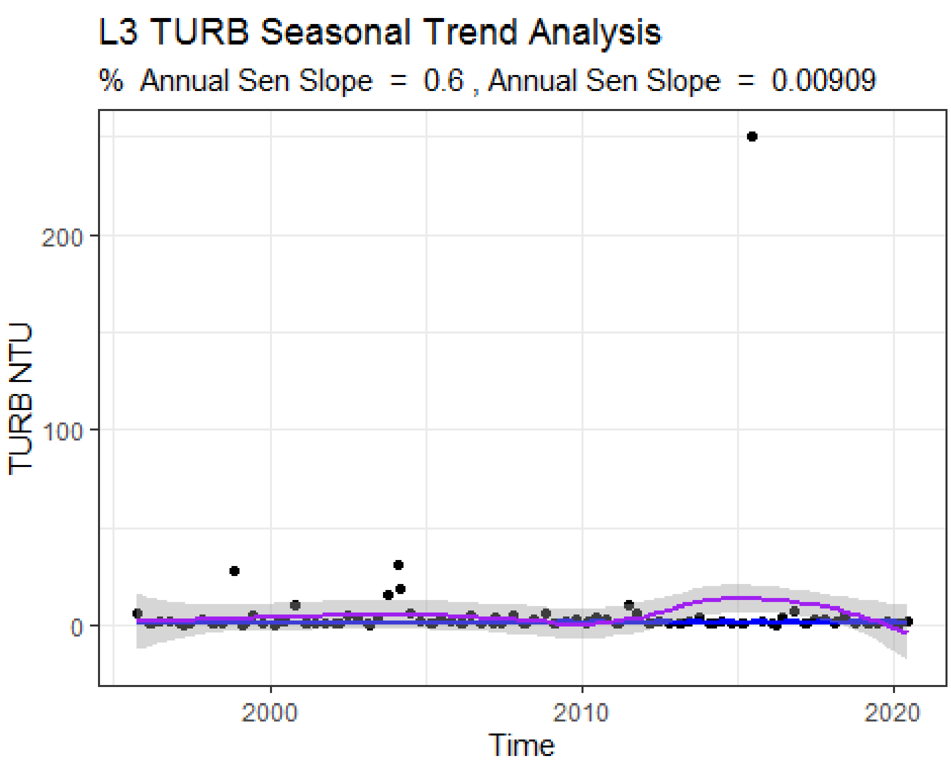

L3 NNN Seasonal Trend Analysis
% Annual Sen Slope = 0 , Annual Sen Slope = 0
NNN g/m3 N
0.0
0.2
0.4
0.6
0.8
2000
2005
2010
2015
2020
Time


L3 SECCHI Seasonal Trend Analysis
% Annual Sen Slope = -0.2 , Annual Sen Slope = -0.00767
SECCHI m
0
2
4
6
2000
2010
2020
Time


L3 TN Seasonal Trend Analysis
% Annual Sen Slope = -0.8 , Annual Sen Slope = -0.00495
TN g/m3 N
0.4
0.8
1.2
2000
2010
2020
Time



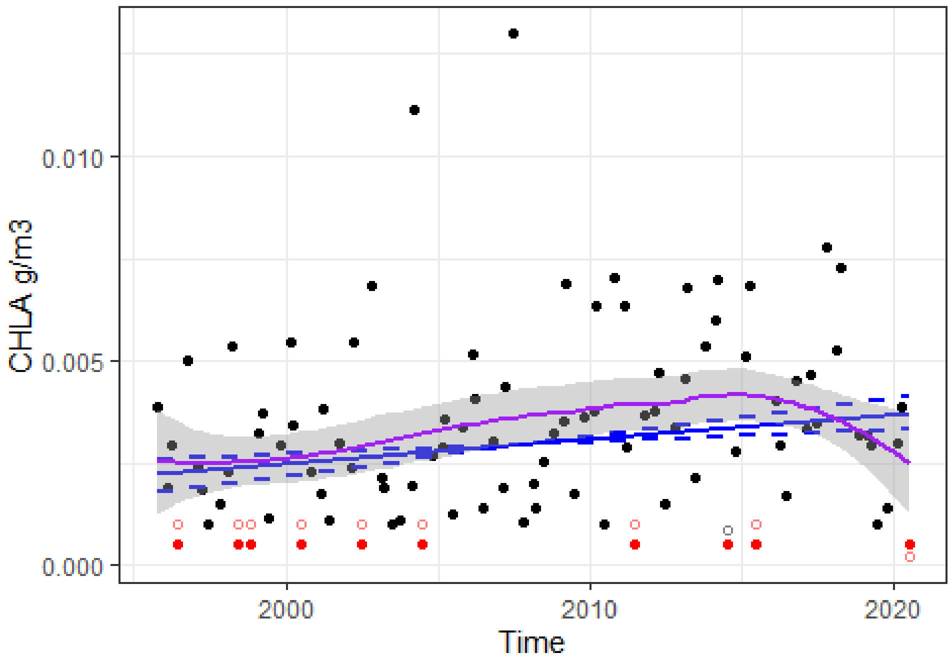
L3 TP Seasonal Trend Analysis
% Annual Sen Slope = 0.8 , Annual Sen Slope = 0.00016
TP g/m3 P
0.3
0.2
0.1
0.0
2000
2010
2020
Time



L3 TURB Seasonal Trend Analysis
% Annual Sen Slope = 0.6 , Annual Sen Slope = 0.00909
TURB NTU
200
100
0
2000
2010
2020
Time

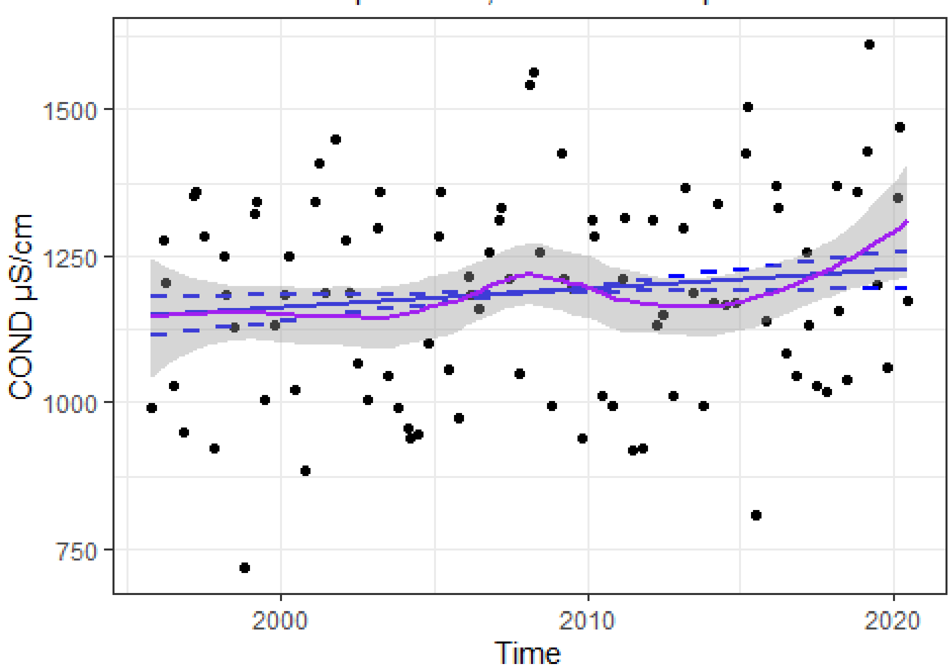
Whole_Lake CHLA Seasonal Trend Analysis

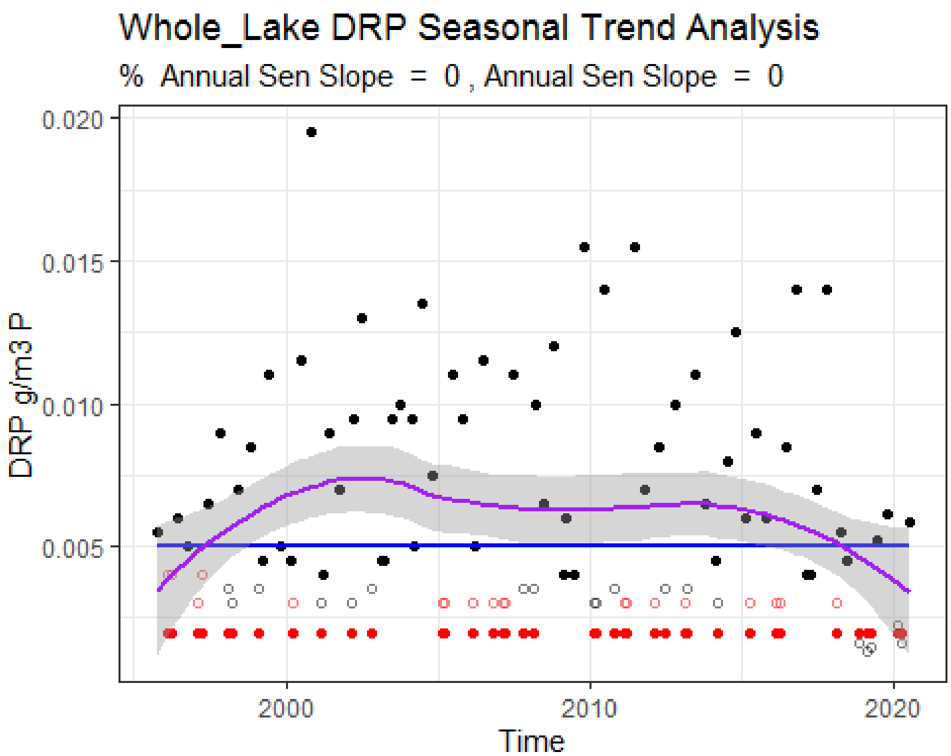
% Annual Sen Slope = 2.1 , Annual Sen Slope = 6.07e-05

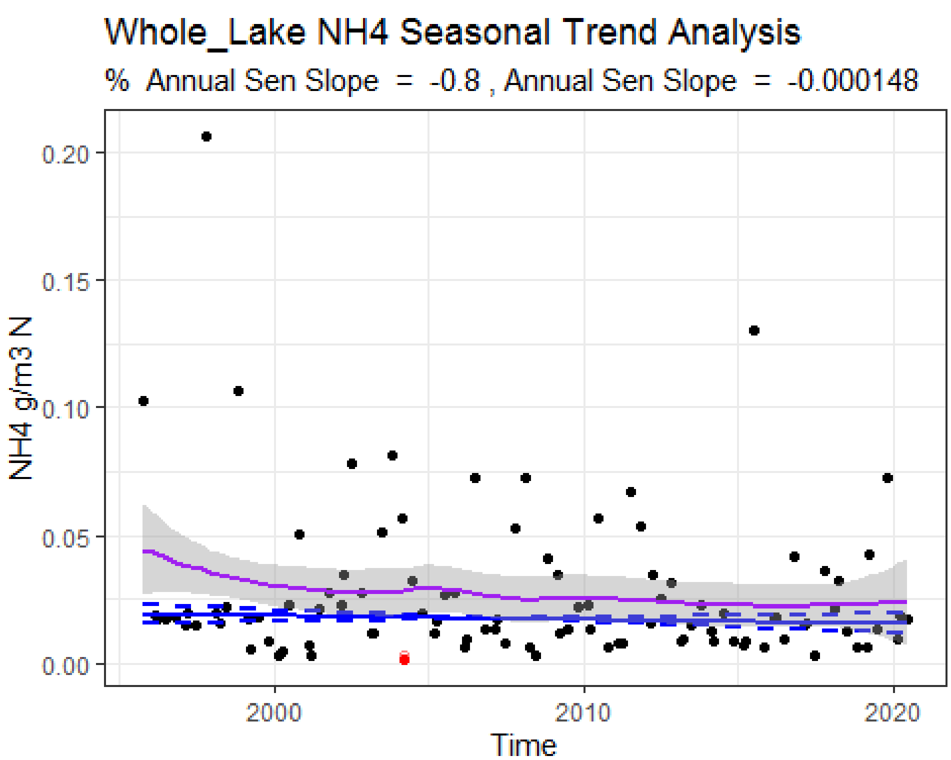


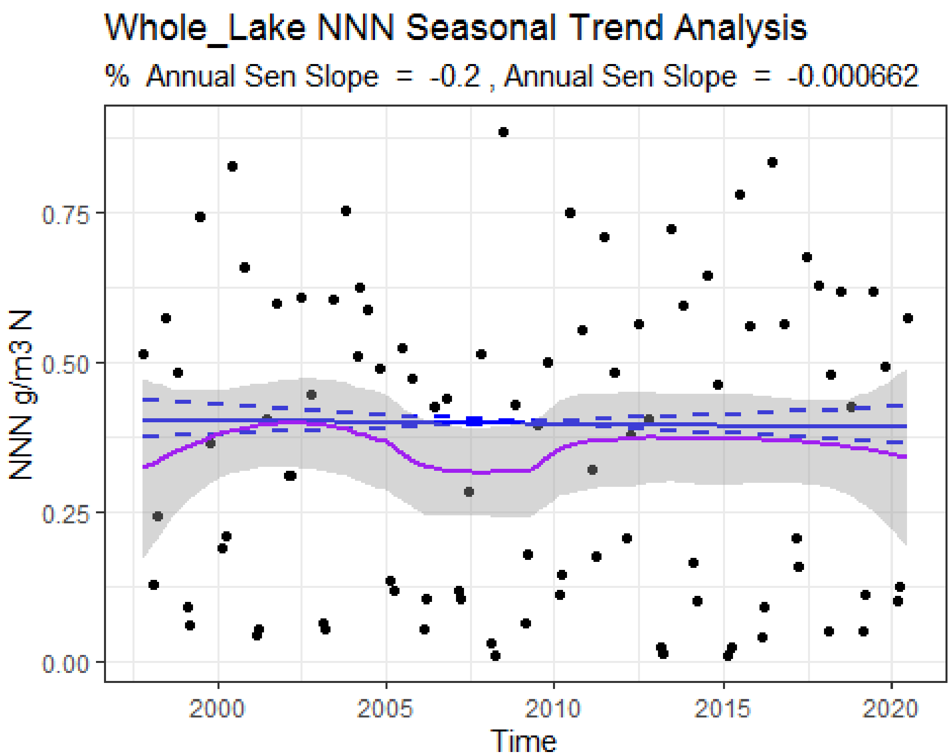
Whole_Lake COND Seasonal Trend Analysis

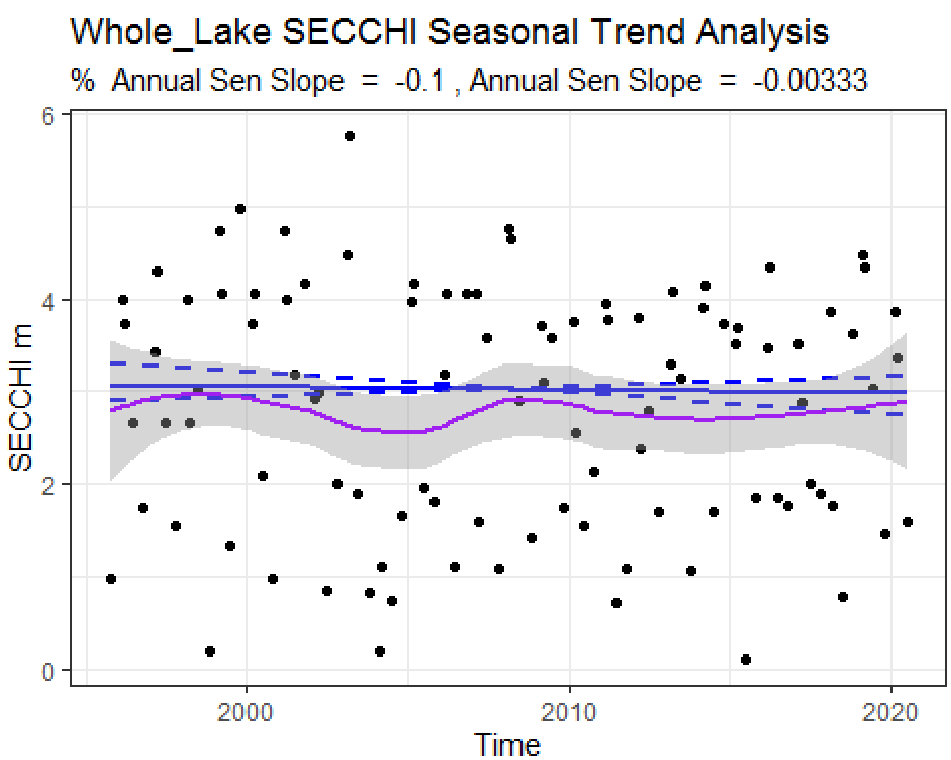
% Annual Sen Slope = 0.3 , Annual Sen Slope = 3.16

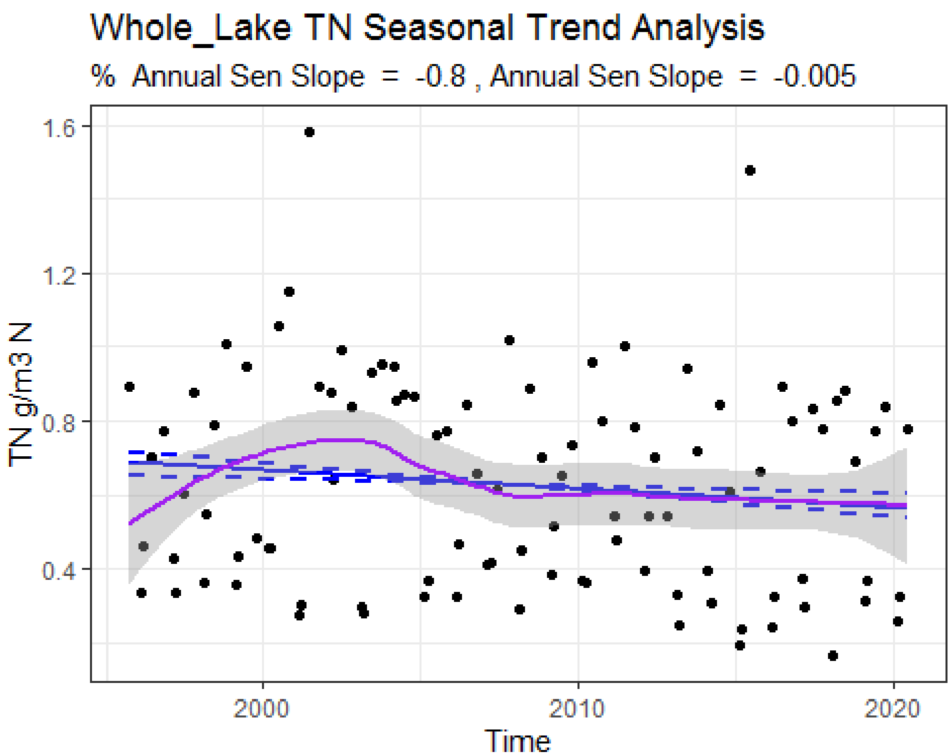



Whole_Lake DRP Seasonal Trend Analysis
% Annual Sen Slope = 0 , Annual Sen Slope = 0
DRP g/m3 P
0.020
0.015
0.010
0.005
2000
2010
2020
Time

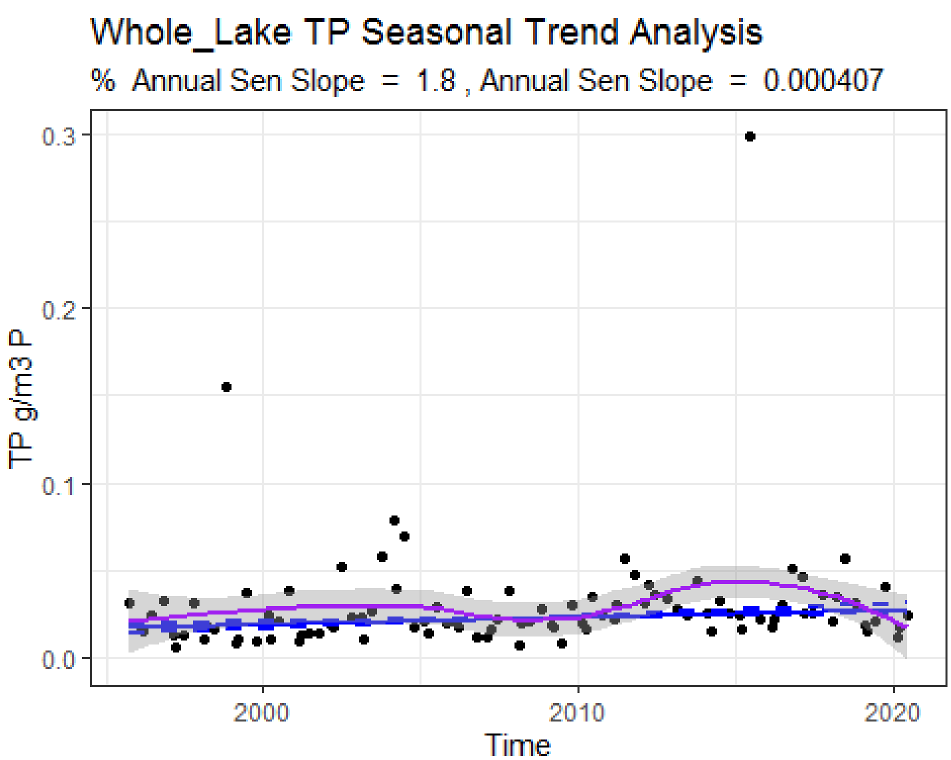

Whole_Lake NH4 Seasonal Trend Analysis
% Annual Sen Slope = -0.8 , Annual Sen Slope = -0.000148
NH4 g/m3 N
0.20
0.15
0.10
0.05
0.00
2000
2010
2020
Time


Whole_Lake NNN Seasonal Trend Analysis
% Annual Sen Slope = -0.2 , Annual Sen Slope = -0.000662
NNN g/m3 N
0.00
0.25
0.50
0.75
2000
2005
2010
2015
2020
Time

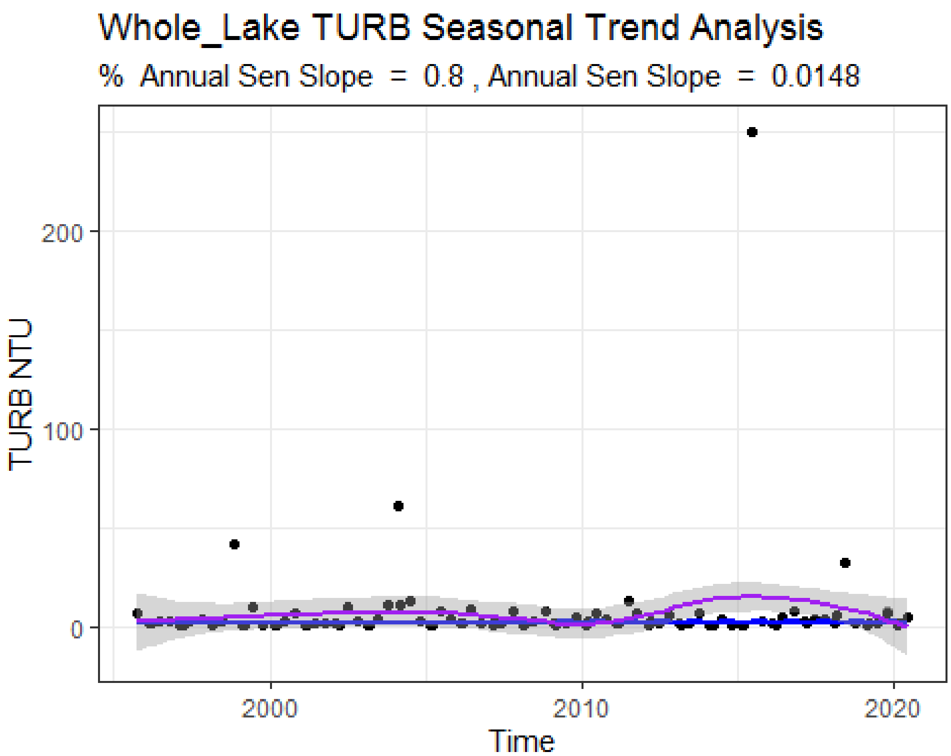

Whole_Lake SECCHI Seasonal Trend Analysis
% Annual Sen Slope = -0.1 , Annual Sen Slope = -0.00333
SECCHI m
0
2
4
6
2000
2010
2020
Time



Whole_Lake TN Seasonal Trend Analysis
% Annual Sen Slope = -0.8 , Annual Sen Slope = -0.005
TN g/m3 N
1.6
1.2
0.8
0.4
2000
2010
2020
Time



Whole_Lake TP Seasonal Trend Analysis
% Annual Sen Slope = 1.8 , Annual Sen Slope = 0.000407
TP g/m3 P
0.3
0.2
0.1
0.0
2000
2010
2020
Time

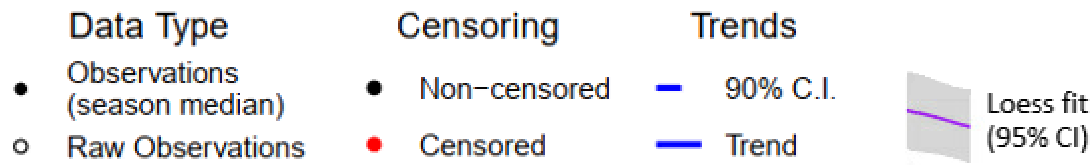


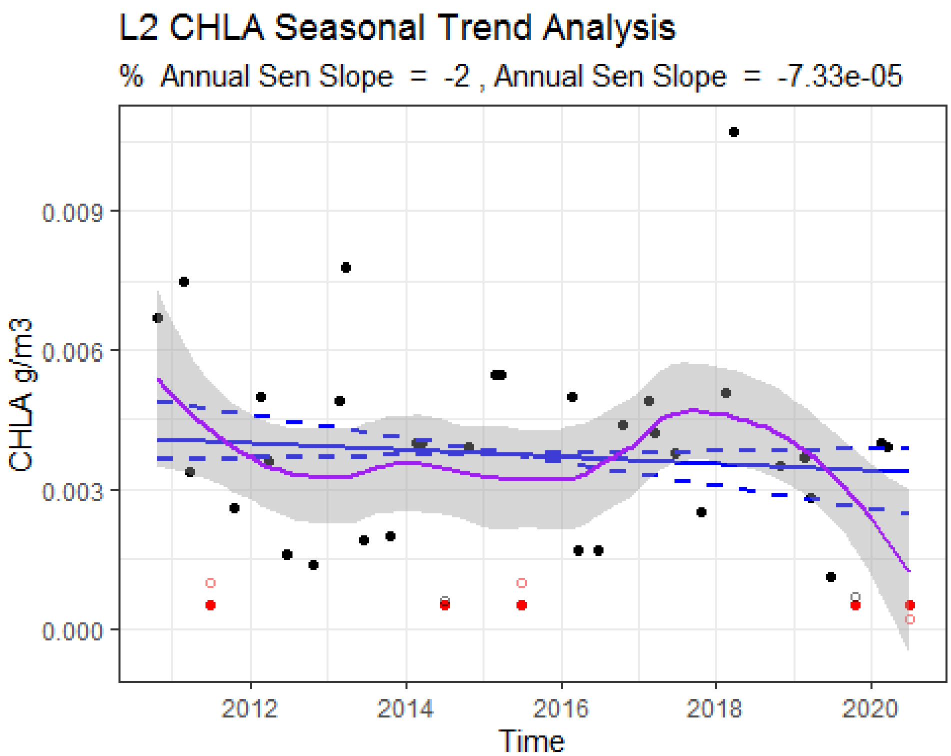
Whole_Lake TURB Seasonal Trend Analysis
% Annual Sen Slope = 0.8 , Annual Sen Slope = 0.0148
TURB NTU
200
100
0
2000
2010
2020
Time

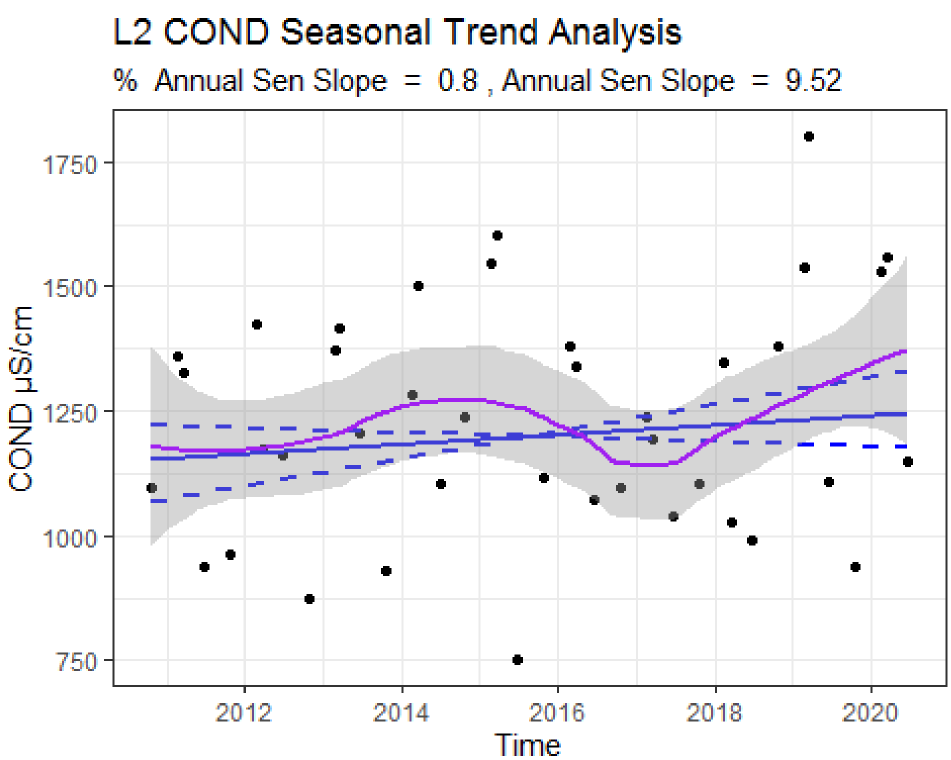
Appendix V

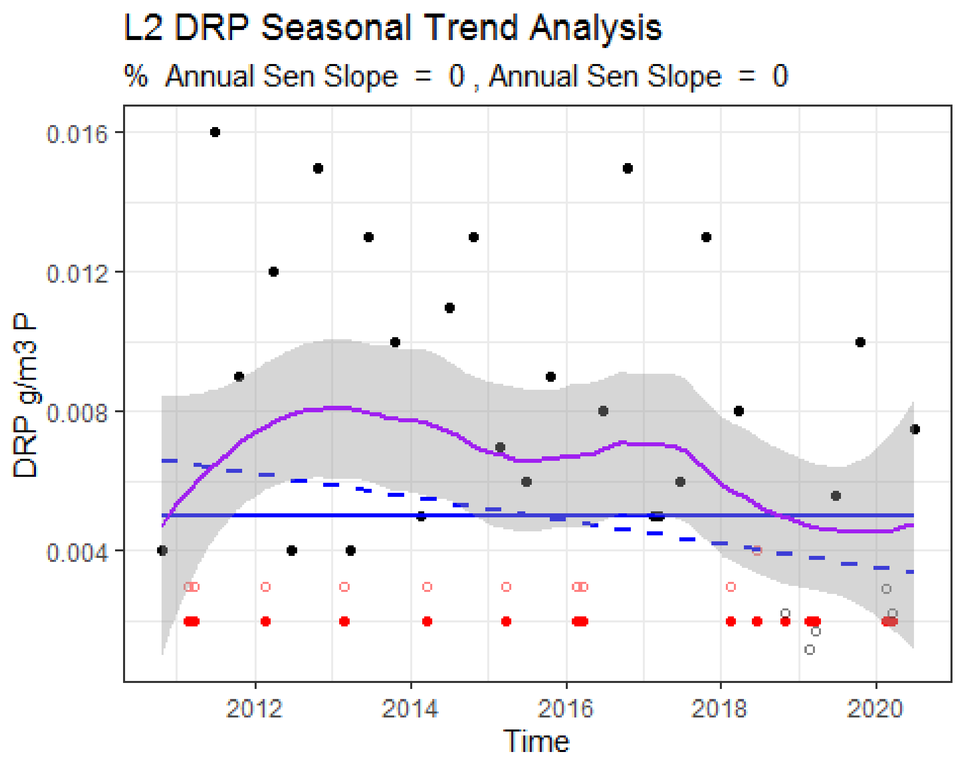
Trend plots for the period 2011-2020

Legend for all trend plots:

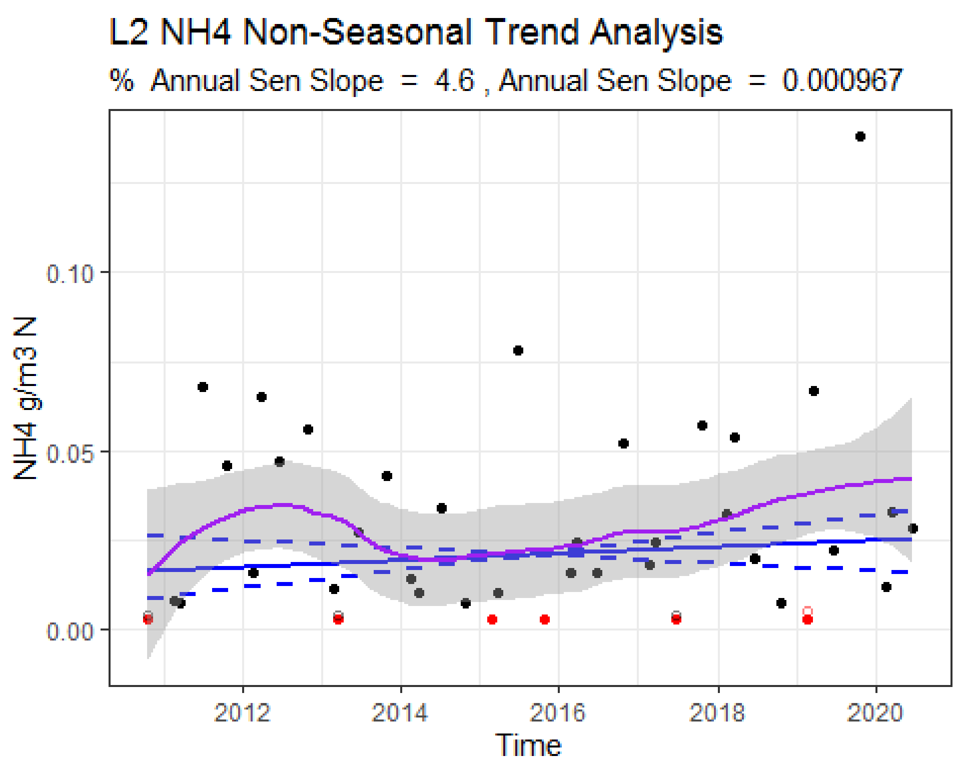



L2 CHLA Seasonal Trend Analysis
% Annual Sen Slope = -2 , Annual Sen Slope = -7.33e-05
0.009
0.006
0.003
0.000
CHLA g/m3
2012
2014
2016
2018
2020
Time

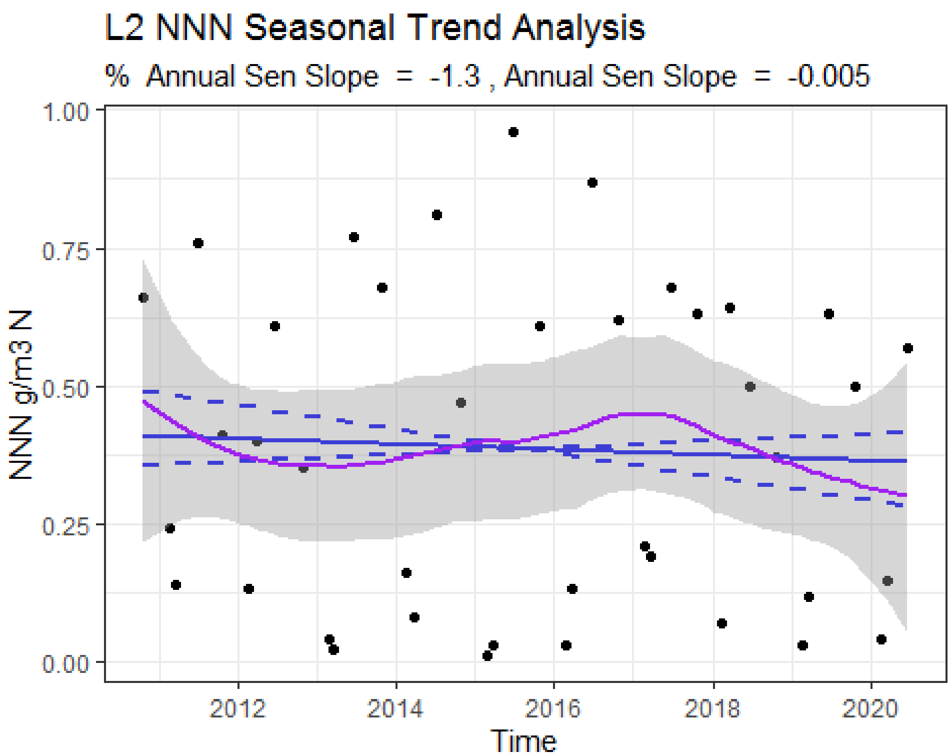

L2 COND Seasonal Trend Analysis
% Annual Sen Slope = 0.8 , Annual Sen Slope = 9.52
1750
1500
1250
1000
750
COND µS/cm
2012
2014
2016
2018
2020
Time

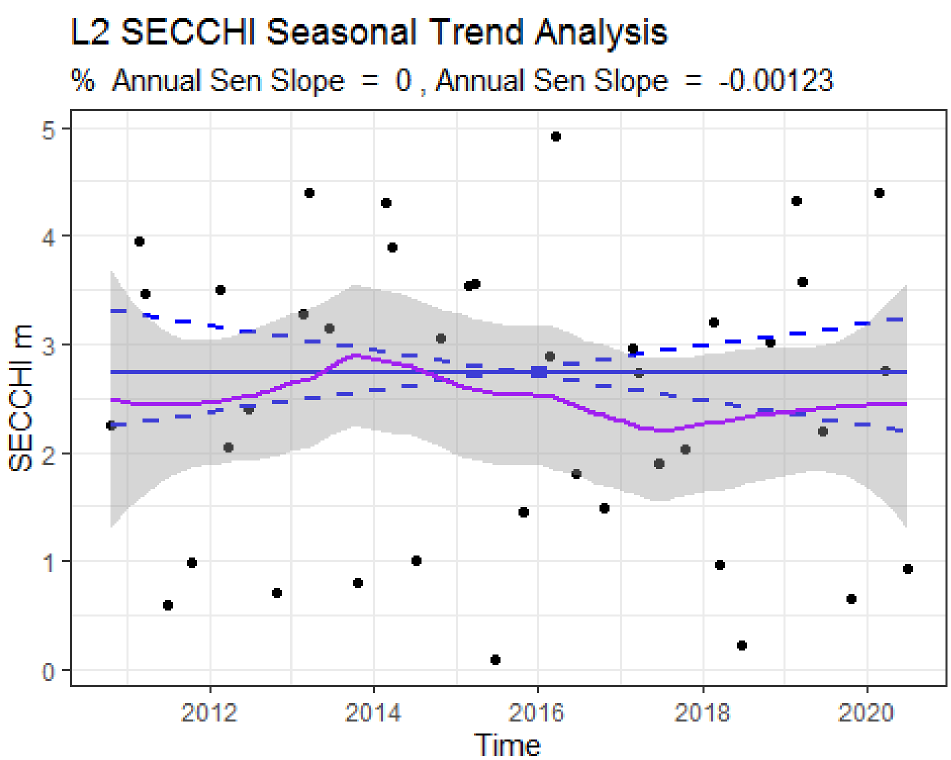


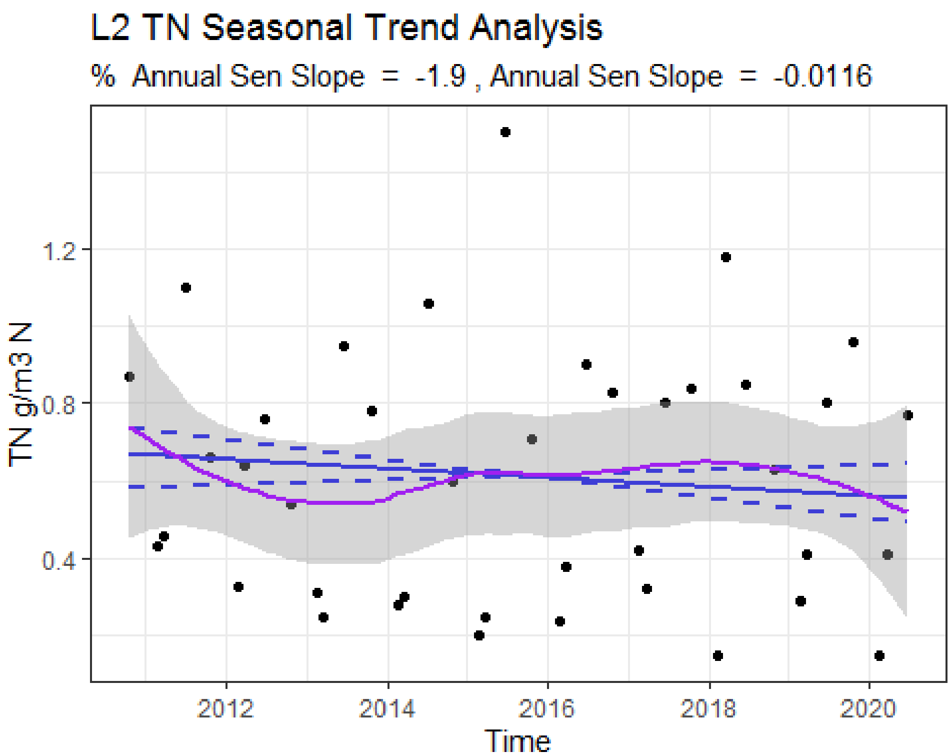
L2 DRP Seasonal Trend Analysis
% Annual Sen Slope = 0 , Annual Sen Slope = 0
DRP g/m3 P
0.016
0.012
0.008
0.004
2012
2014
2016
2018
2020
Time

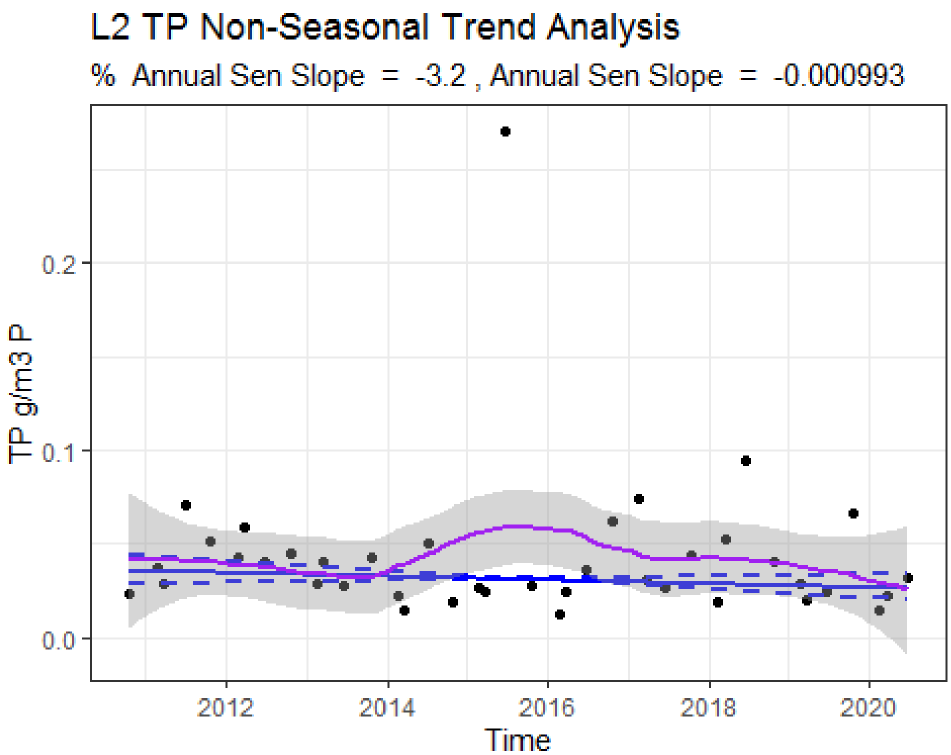


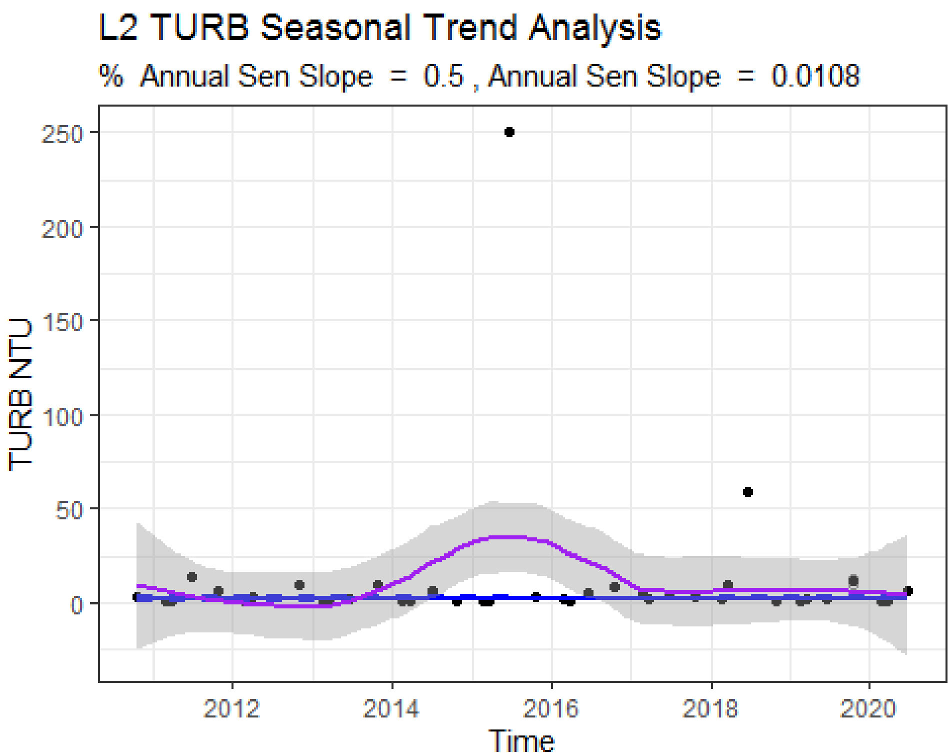
L2 NH4 Non-Seasonal Trend Analysis
% Annual Sen Slope = 4.6 , Annual Sen Slope = 0.000967
NH4 g/m3 N
0.10
0.05
0.00
2012
2014
2016
2018
2020
Time

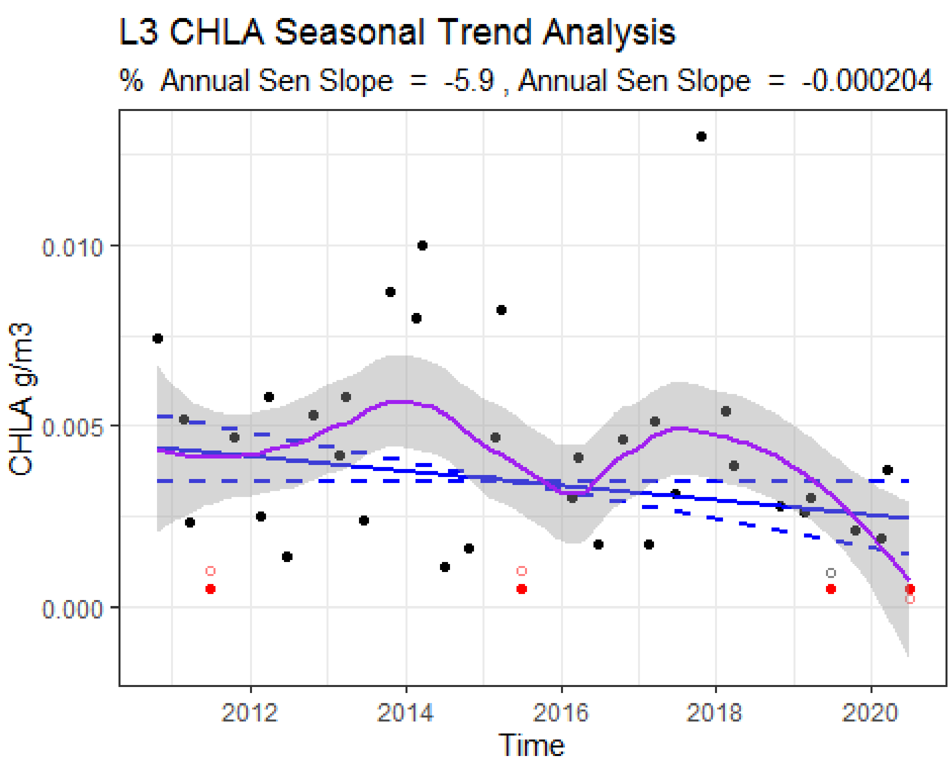

L2 NNN Seasonal Trend Analysis
% Annual Sen Slope = -1.3 , Annual Sen Slope = -0.005
NNN g/m3 N
1.00
0.75
0.50
0.25
0.00
2012
2014
2016
2018
2020
Time

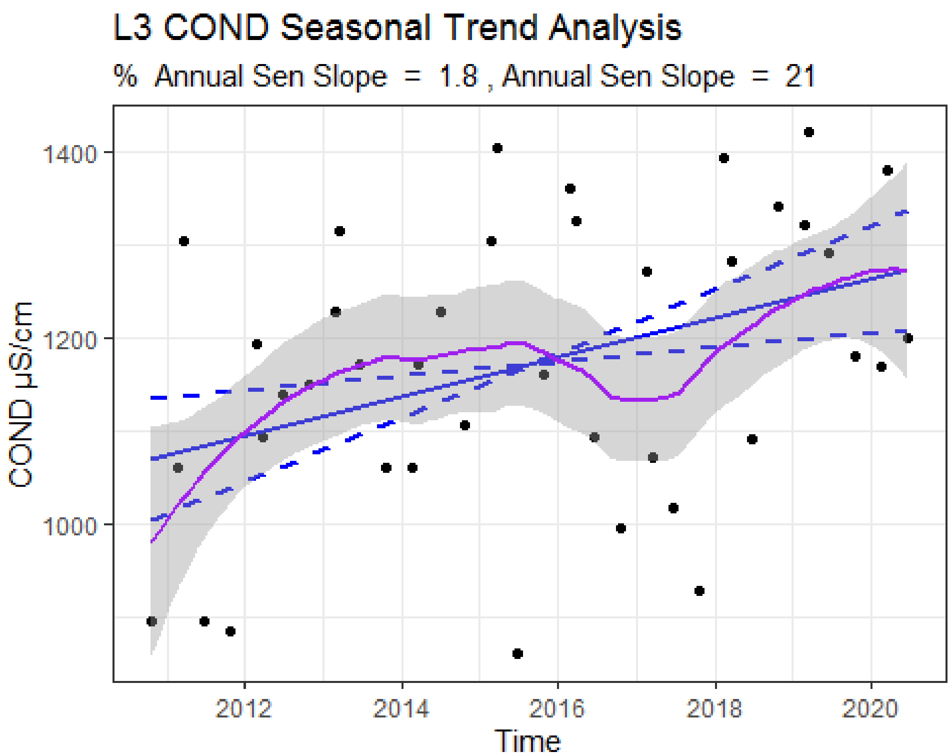

L2 SECCHI Seasonal Trend Analysis
% Annual Sen Slope = 0 , Annual Sen Slope = -0.00123
SECCHI m
5
4
3
2
1
0
2012
2014
2016
2018
2020
Time


L2 TN Seasonal Trend Analysis
% Annual Sen Slope = -1.9 , Annual Sen Slope = -0.0116
TN g/m3 N
1.2
0.8
0.4
2012
2014
2016
2018
2020
Time

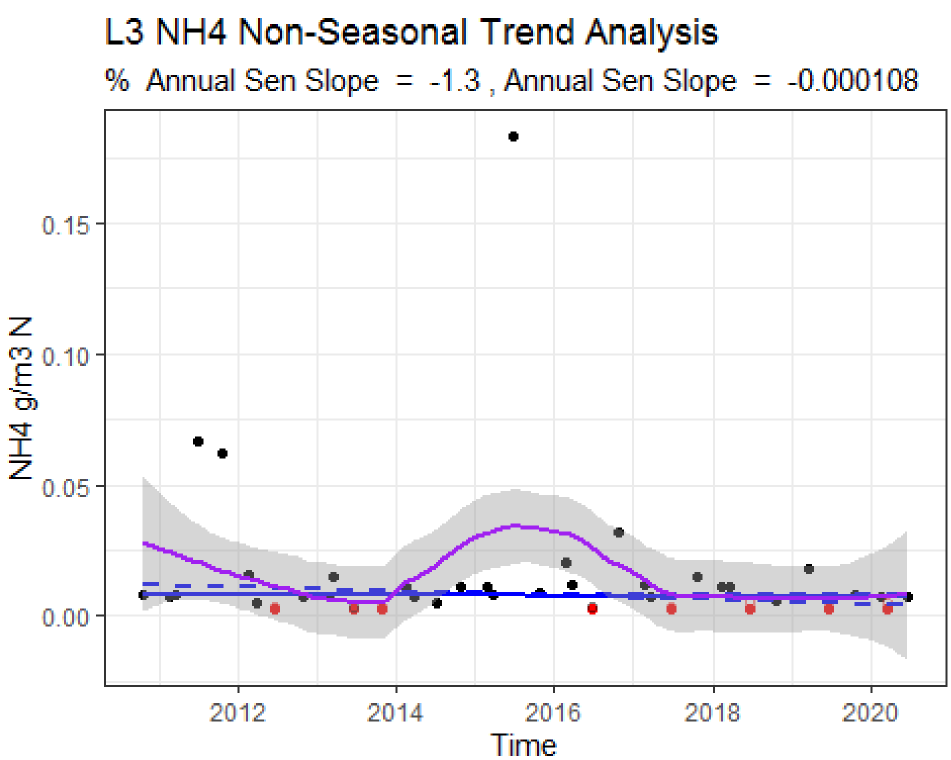

L2 TP Non-Seasonal Trend Analysis
% Annual Sen Slope = -3.2 , Annual Sen Slope = -0.000993
TP g/m3 P
0.2
0.1
0.0
2012
2014
2016
2018
2020
Time


L2 TURB Seasonal Trend Analysis
% Annual Sen Slope = 0.5 , Annual Sen Slope = 0.0108
TURB NTU
250
200
150
100
50
0
2012
2014
2016
2018
2020
Time

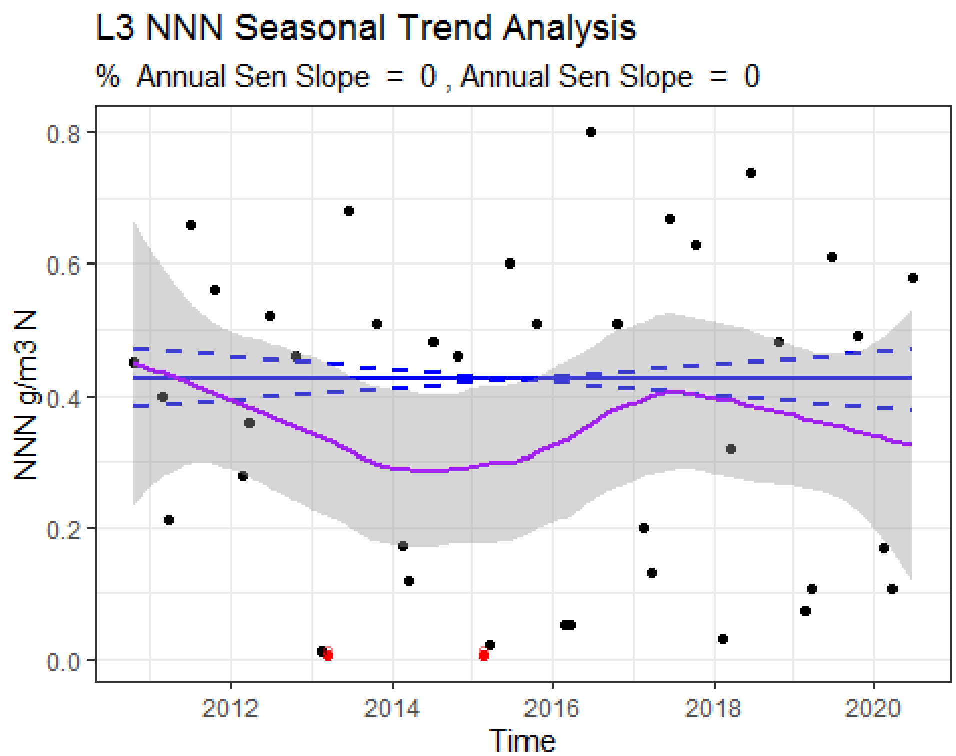

L3 CHLA Seasonal Trend Analysis
% Annual Sen Slope = -5.9 , Annual Sen Slope = -0.000204
CHLA g/m3
0.010
0.005
0.000
2012
2014
2016
2018
2020
Time

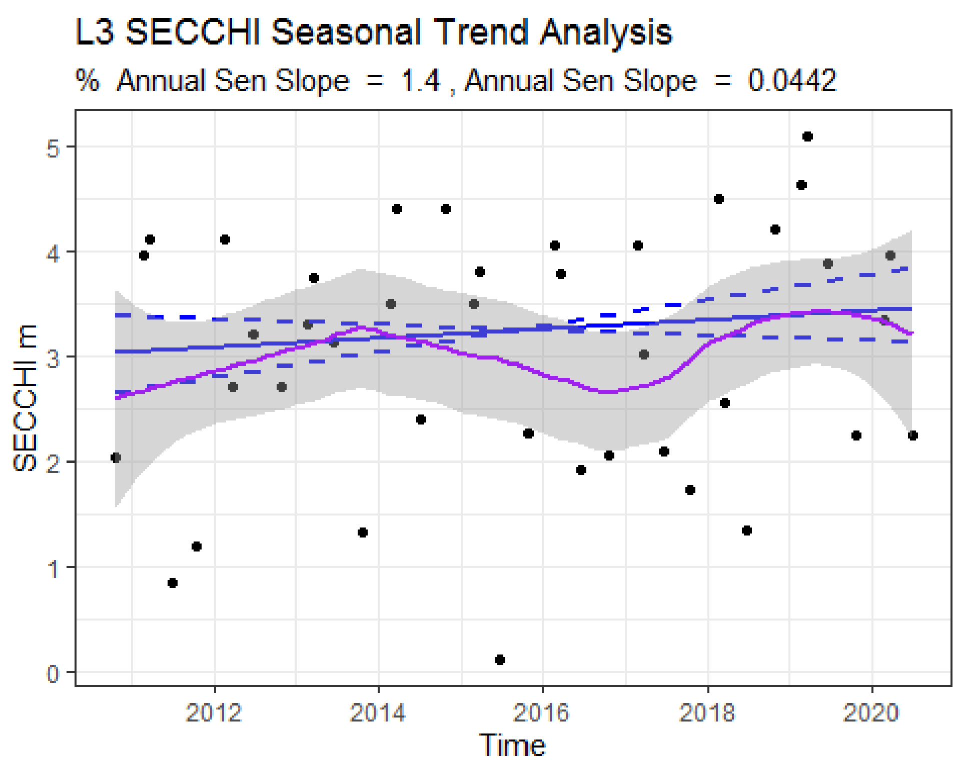


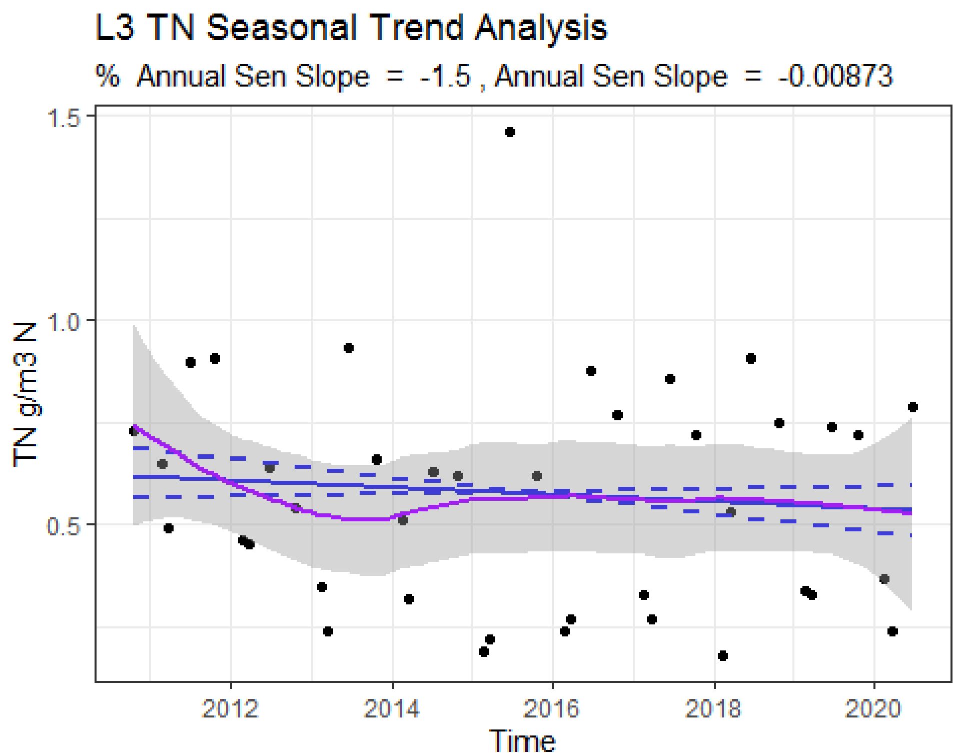
L3 COND Seasonal Trend Analysis
% Annual Sen Slope = 1.8 , Annual Sen Slope = 21
1400
1200
1000
COND µS/cm
2012
2014
2016
2018
2020
Time

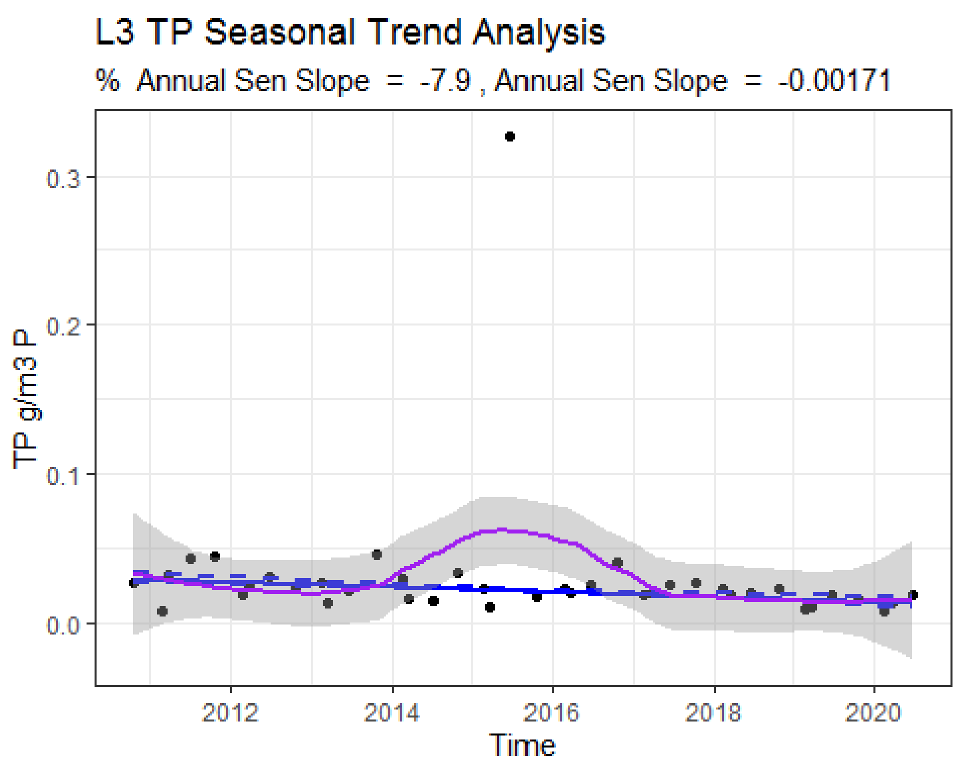


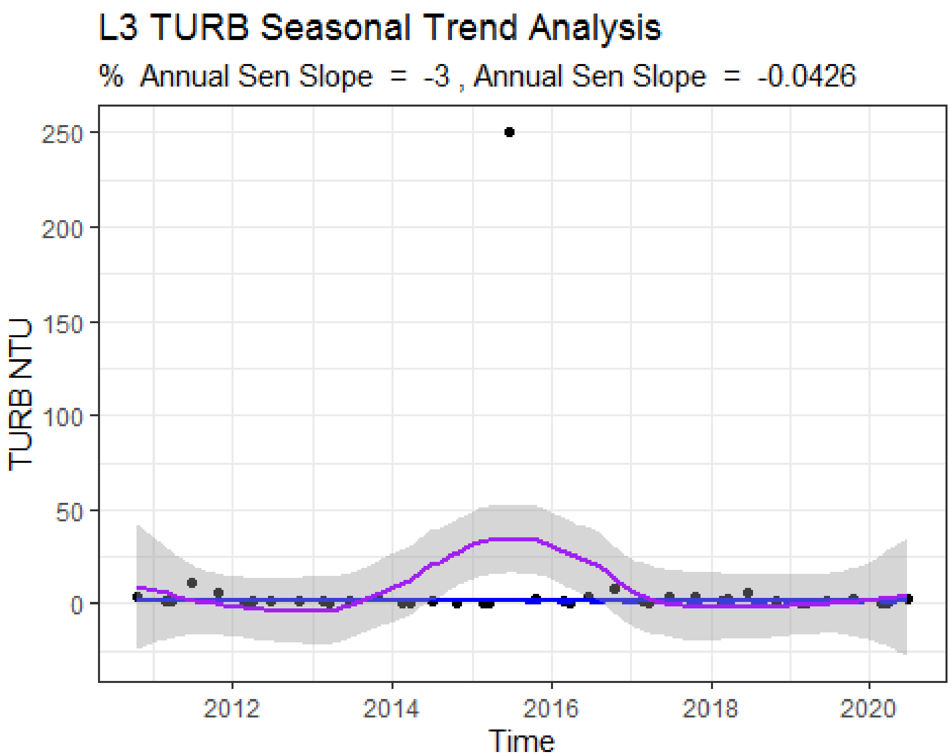
L3 NH4 Non-Seasonal Trend Analysis
% Annual Sen Slope = -1.3 , Annual Sen Slope = -0.000108
0.15
0.10
0.05
0.00
NH4 g/m3 N
2012
2014
2016
2018
2020
Time


L3 NNN Seasonal Trend Analysis
% Annual Sen Slope = 0 , Annual Sen Slope = 0
NNN g/m3 N
0.0
0.2
0.4
0.6
0.8
2012
2014
2016
2018
2020
Time

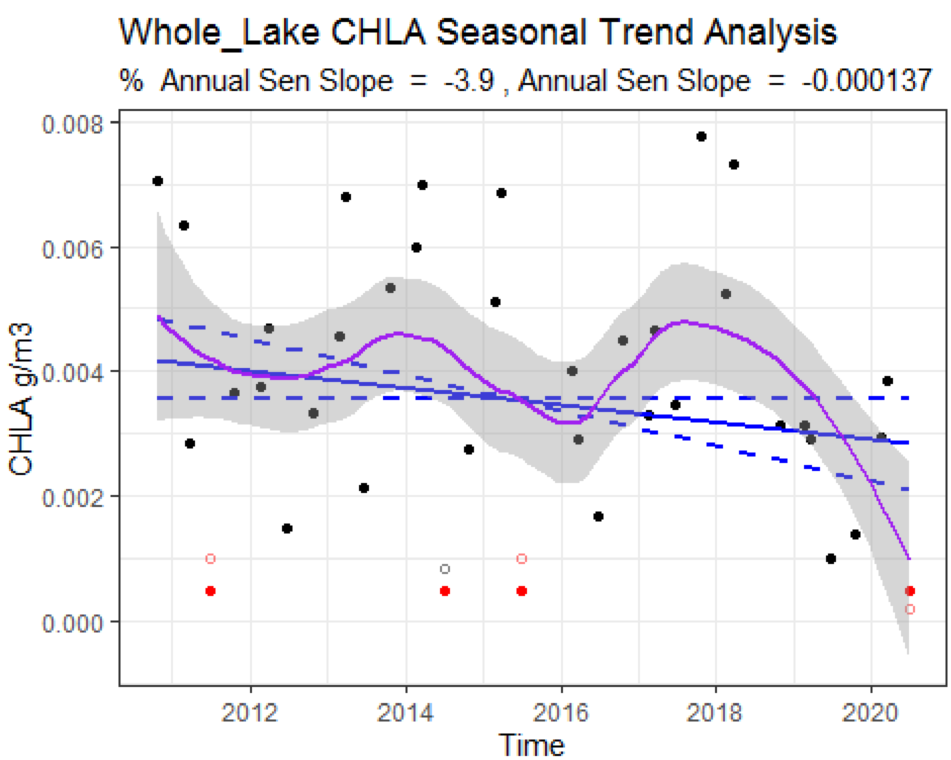

L3 SECCHI Seasonal Trend Analysis
% Annual Sen Slope = 1.4 , Annual Sen Slope = 0.0442
SECCHI m
0
1
2
3
4
5
2012
2014
2016
2018
2020
Time


L3 TN Seasonal Trend Analysis
% Annual Sen Slope = -1.5 , Annual Sen Slope = -0.00873
TN g/m3 N
1.5
1.0
0.5
2012
2014
2016
2018
2020
Time

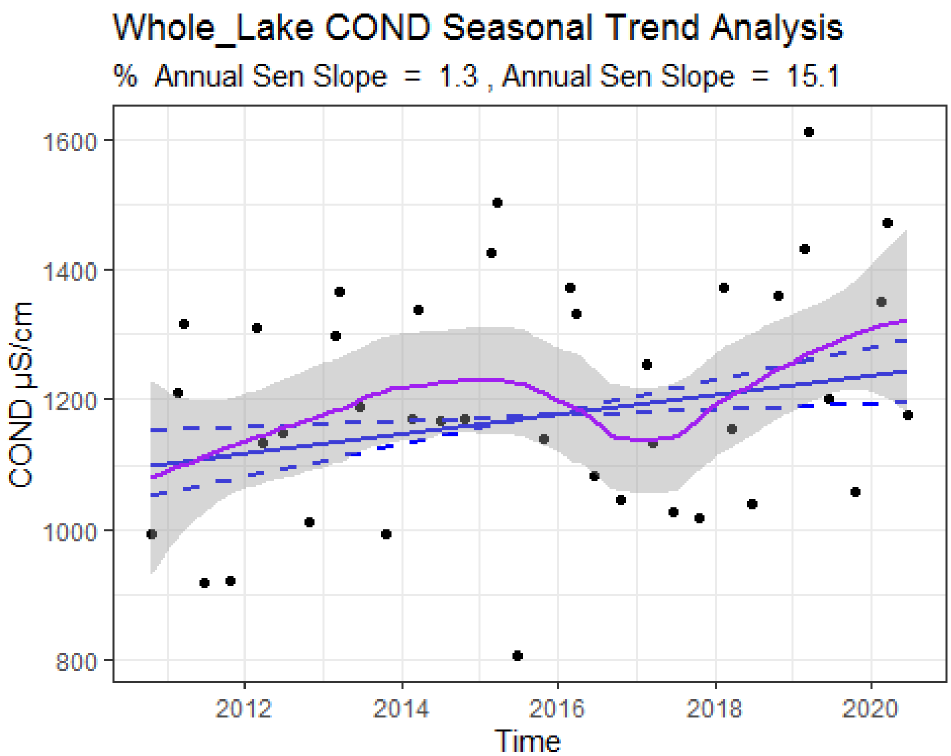

L3 TP Seasonal Trend Analysis
% Annual Sen Slope = -7.9 , Annual Sen Slope = -0.00171
TP g/m3 P
0.3
0.2
0.1
0.0
2012
2014
2016
2018
2020
Time



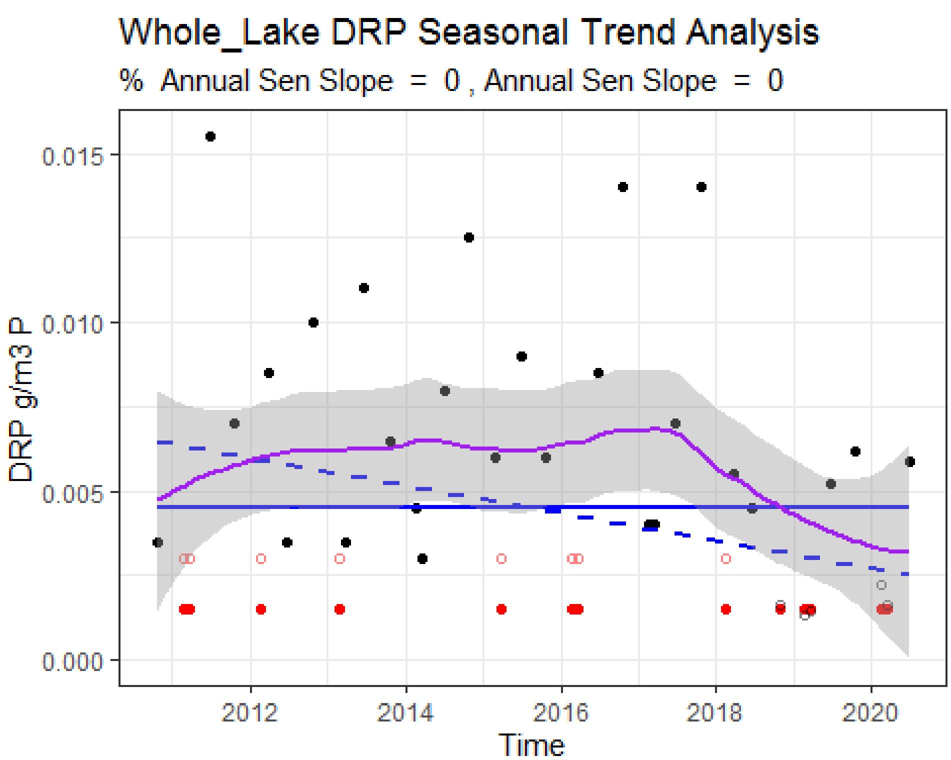
L3 TURB Seasonal Trend Analysis
% Annual Sen Slope = -3 , Annual Sen Slope = -0.0426
250
200
150
100
50
0
TURB NTU
2012
2014
2016
2018
2020
Time



Whole_Lake CHLA Seasonal Trend Analysis
% Annual Sen Slope = -3.9 , Annual Sen Slope = -0.000137
0.008
0.006
0.004
0.002
0.000
CHLA g/m3
2012
2014
2016
2018
2020
Time



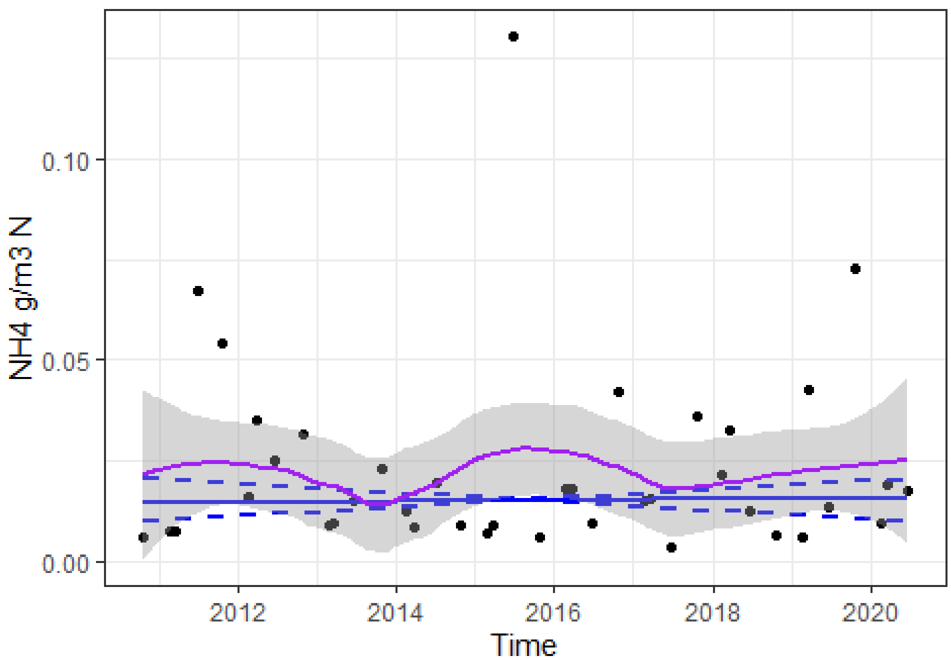
Whole_Lake COND Seasonal Trend Analysis
% Annual Sen Slope = 1.3 , Annual Sen Slope = 15.1
COND µS/cm
1600
1400
1200
1000
800
2012
2014
2016
2018
2020
Time



Whole_Lake DRP Seasonal Trend Analysis
% Annual Sen Slope = 0 , Annual Sen Slope = 0
DRP g/m3 P
0.015
0.010
0.005
0.000
2012
2014
2016
2018
2020
Time

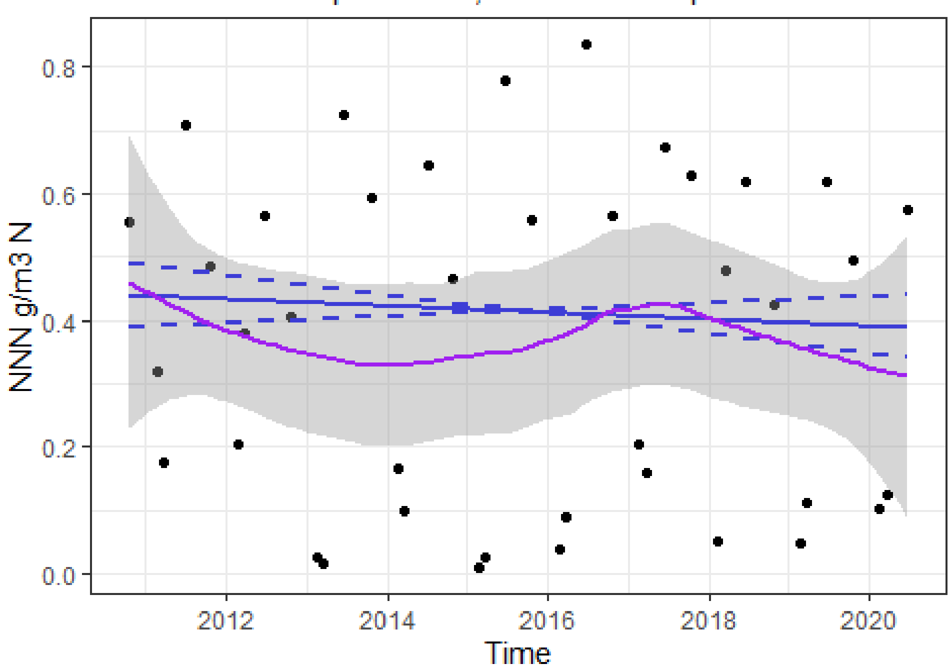
Whole_Lake NH4 Non-Seasonal Trend Analysis

% Annual Sen Slope = 0.9 , Annual Sen Slope = 0.000142



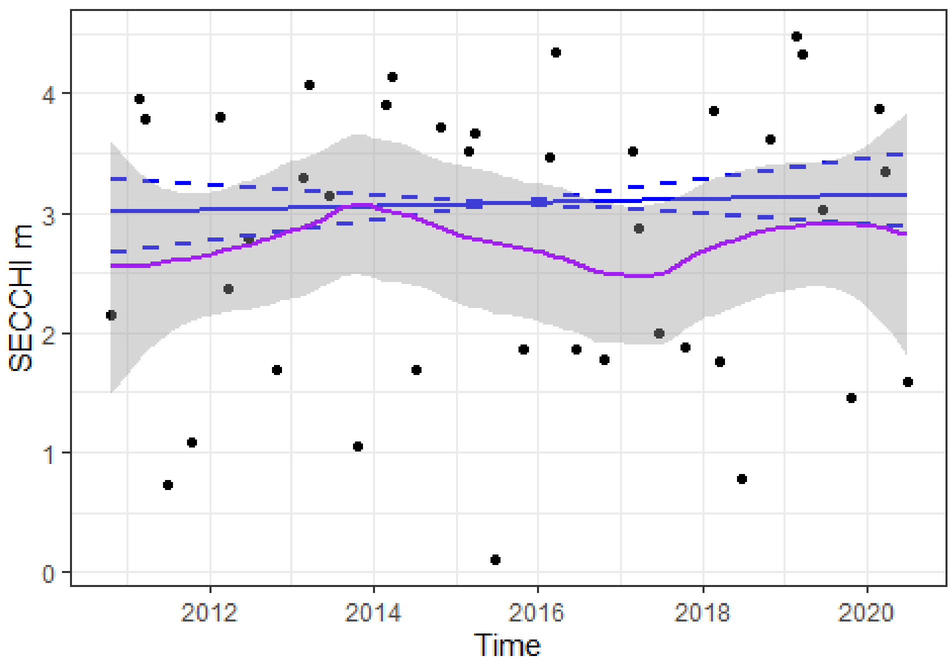
Whole_Lake NNN Seasonal Trend Analysis

% Annual Sen Slope = -1.2 , Annual Sen Slope = -0.00501



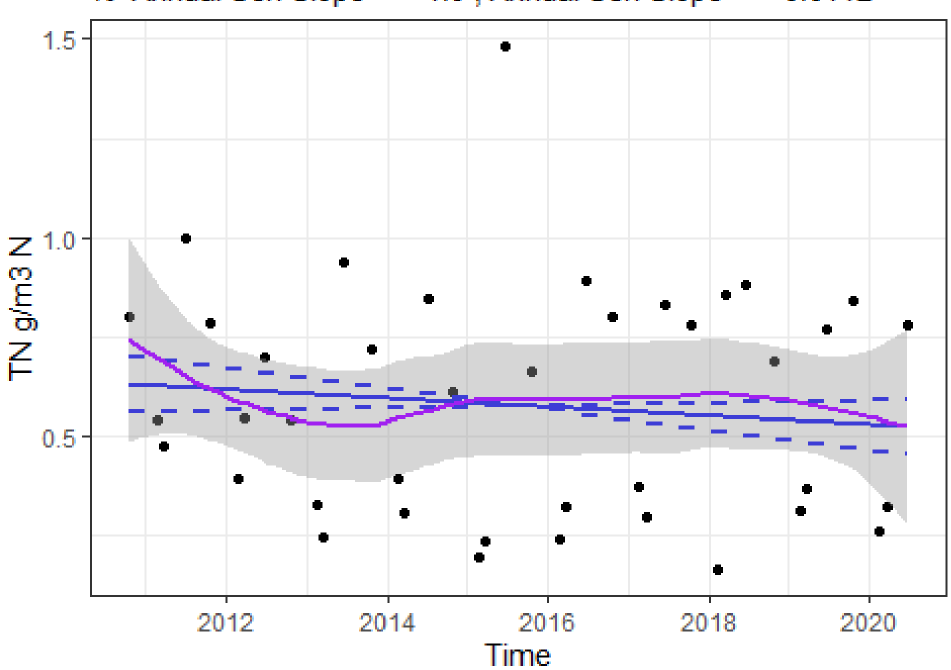
Whole_Lake SECCHI Seasonal Trend Analysis

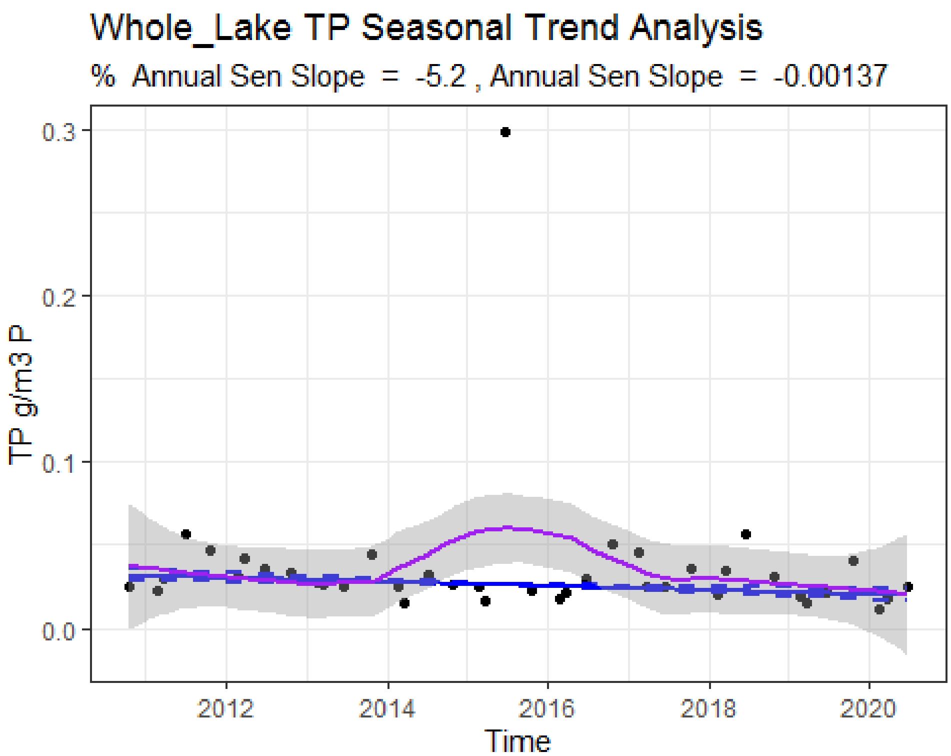
% Annual Sen Slope = 0.5 , Annual Sen Slope = 0.0151

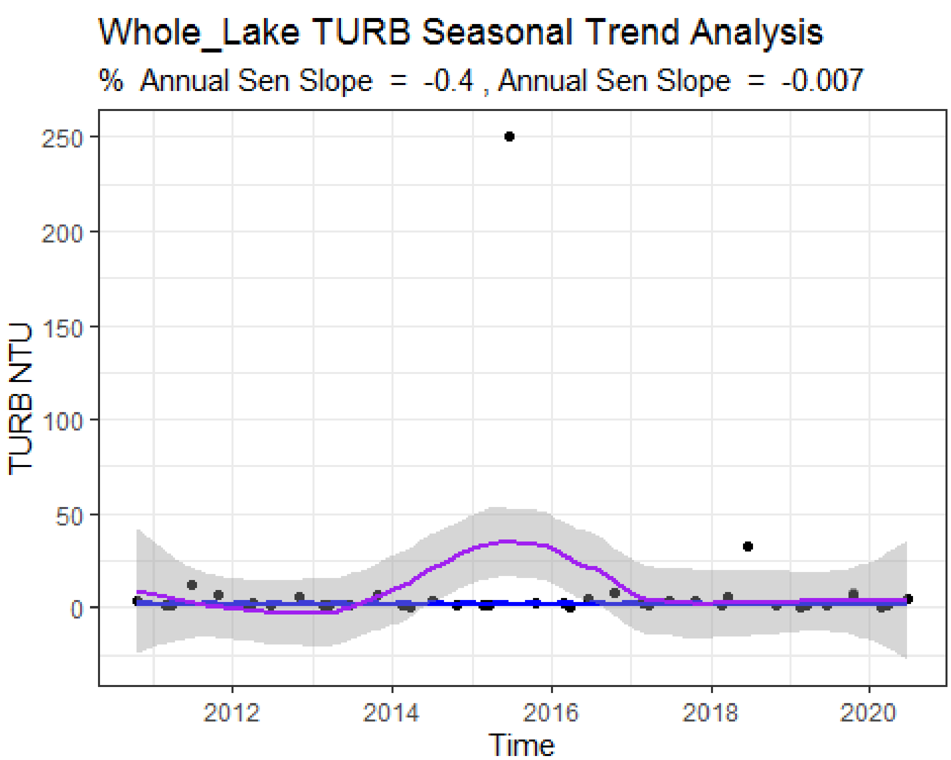


Whole_Lake TN Seasonal Trend Analysis

% Annual Sen Slope = -1.9 , Annual Sen Slope = -0.0112




Whole_Lake TP Seasonal Trend Analysis
% Annual Sen Slope = -5.2 , Annual Sen Slope = -0.00137
TP g/m3 P
0.3
0.2
0.1
0.0
2012
2014
2016
2018
2020
Time


Whole_Lake TURB Seasonal Trend Analysis
% Annual Sen Slope = -0.4 , Annual Sen Slope = -0.007
TURB NTU
250
200
150
100
50
0
2012
2014
2016
2018
2020
Time

Appendix VI

Comparison of trends reported using a significance based and a confidence based interpretation

Comparison between the results of the confidence grading system and the previous p-value based significance method. Significant trends based on p-values are identified in green text, while trends with high confidence are identified in red (increasing trend) or green (decreasing trend) text

Site	No. of Surveys	Seasonality	Proportion Censored	Analysis Note	S Stat	tau	p-value	Median Sen Slope	Percent Annual Change	Trend Direction	Confidence Trend Decreasing
CHLA											
L2	98	Seasonal	0.16		217	0.188	0.00809	0.00005	1.79	Increasing	Exceptionally unlikely
L3	98	Seasonal	0.13		211	0.183	0.00996	0.00004	1.70	Increasing	Exceptionally unlikely
Whole Lake	98	Seasonal	0.10		269	0.234	0.00114	0.00006	2.06	Increasing	Exceptionally unlikely
COND											
L2	100	Seasonal	0.00		106	0.088	0.21933	0.27599	0.23	Increasing	Unlikely
L3	100	Seasonal	0.00		190	0.158	0.02697	0.37984	0.32	Increasing	Extremely unlikely
Whole Lake	100	Seasonal	0.00		190	0.158	0.02713	0.31594	0.27	Increasing	Extremely unlikely
DRP											
L2	100	Seasonal	0.34	Sen slope influenced by censored values	-11	-0.009	0.89908	0.00000	0.00	Decreasing	As likely as not
L3	100	Seasonal	0.45	Sen slope influenced by censored values	-108	-0.090	0.15455	0.00000	0.00	Decreasing	Very likely
Whole Lake	100	Seasonal	0.38	Sen slope influenced by censored values	-23	-0.019	0.77688	0.00000	0.00	Decreasing	As likely as not
NH4											
L2	100	Seasonal	0.10	Sen slope influenced by censored values	0	0.000	1	0.00000	0.00	Indeterminant	As likely as not
L3	100	Seasonal	0.17		-184	-0.153	0.0308	-0.00027	-2.48	Decreasing	Extremely likely
Whole Lake	100	Seasonal	0.01		-71	-0.059	0.4134	-0.00015	-0.85	Decreasing	Likely
NNN											
L2	92	Seasonal	0.00		-60	-0.059	0.43498	-0.00138	-0.37	Decreasing	Likely
L3	92	Seasonal	0.02	Sen slope based on tied non-censored values	-3	-0.003	0.97886	0.00000	0.00	Decreasing	As likely as not

Site	No. of Surveys	Seasonality	Proportion Censored	Analysis Note	S Stat	tau	p-value	Median Sen Slope	Percent Annual Change	Trend Direction	Confidence Trend Decreasing
Whole Lake	92	Seasonal	0.00		-25	-0.025	0.75115	-0.00066	-0.17	Decreasing	As likely as not
SECCHI											
L2	100	Seasonal	0.00		-55	-0.046	0.52812	-0.00892	-0.33	Decreasing	Likely
L3	100	Seasonal	0.00		-63	-0.052	0.46845	-0.00767	-0.25	Decreasing	Likely
Whole Lake	100	Seasonal	0.00		-25	-0.021	0.77923	-0.00333	-0.11	Decreasing	As likely as not
TN											
L2	100	Seasonal	0.00		-194	-0.162	0.02399	-0.00500	-0.80	Decreasing	Extremely likely
L3	100	Seasonal	0.00		-198	-0.165	0.02122	-0.00495	-0.81	Decreasing	Extremely likely
Whole Lake	100	Seasonal	0.00		-223	-0.186	0.00949	-0.00500	-0.80	Decreasing	Virtually certain
TP											
L2	100	Seasonal	0.00		325	0.271	0.00015	0.00057	2.31	Increasing	Exceptionally unlikely
L3	100	Seasonal	0.00		129	0.108	0.13393	0.00016	0.84	Increasing	Very unlikely
Whole Lake	100	Seasonal	0.00		256	0.213	0.00288	0.00041	1.79	Increasing	Exceptionally unlikely
TURB											
L2	100	Seasonal	0.00		140	0.117	0.10411	0.02227	0.97	Increasing	Very unlikely
L3	100	Seasonal	0.00		95	0.079	0.27172	0.00909	0.61	Increasing	Unlikely
Whole Lake	100	Seasonal	0.00		128	0.107	0.13778	0.01484	0.82	Increasing	Very unlikely

Appendix VII

Comparison of currently and previously reported trends

Significant changes to the data analysis methodology have been made in the current report. Previously LakeWatch software has been used for analysis and it is no longer being supported. Moving away from using the LakeWatch analysis software has provided the opportunity to review and update the analytical methods used. The main changes can be summarised as follows:

1. The data period used for the full record has been taken as beginning in the 1996 monitoring year, while previously the record used began in 1990. This change has been made due to changes to the monitoring being standardised in 1996. The monitoring programme has remained relatively unchanged since this time. Differences in the timing of data collection prior to 1996 means that the sampling was not consistently targeting the stratification conditions that the programme was designed around.
2. The annual period for the calculation of TLI has been shifted from the calendar year to align with the monitoring year (July-June). This change provides a more robust assessment of the trophic level of the lake, which should be assessed on complete stratification cycles (Burns, 2000). Previously, the period of one stratification cycle would have been split across two years. Because the nature of stratification does not allow for mixing between layers of the water column, particular changes in the water chemistry occur in a predictable fashion during the stratified period. This means that these cyclical changes were not incorporated into the annual TLI value in a holistic manner. Furthermore, this change has aligned the period over which the TLI is calculated with the reporting period used by the Council, so that reporting of TLI and trend analyses are no longer calculated for only the first half of the reporting period. Although Burns et al., (2000) and Schallenberg & van der Zon (2021) recommend using a September to August calculation period to best align with the stratification cycle, in this instance the standardised sampling regime used in Lake Rotorangi does not include sampling between July-October. Because of this the calculation on the existing dataset will provide the same result whether the annual period starts in July or September.
3. A Mann-Kendall or seasonal Kendall test is now used for trend analysis (dependent on the results of a Kruskal-Wallis test for seasonality). This has replaced a seasonal linear regression. This change has been made due to the non-normal distribution of the data studied. Linear regression is a parametric technique, which relies on the data being (approximately) normally distributed. It is thus more appropriate to use non-parametric analytical methods.
4. Previous interpretation of the linear regression was made using the p-value for the f-statistic, which tests whole regression fit. To test change over time, it is more appropriate to test the p-value of the regression slope. Doing so in the past would also have given linear regression results that are more similar to those of the Mann-Kendall test (see Appendix V for a comparison).
5. Left censored data (data points below detection limits) were previously analysed by replacing these values with half the detection limit. In the current period, censored data has been replaced using a regression on order statistics (ROS) model when calculating summary statistics. This creates a distribution of the censored data based on the data above the detection limit. While this is a more robust method, care should be taken when interpreting statistics below the detection limit. For this reason, suspended solids for which approximately two-thirds of the data is censored, has been excluded from the analysis.
6. Epilimnion data is now used in trend analysis. Although Lakewatch stated that epilimnion data was trended during stratified periods and all data during isothermal periods, subsequent discrepancies in data have revealed that previously all data from all lake layers was being included in trend analysis. The trend analysis has been updated to include only epilimnetic data for the majority of variables, which is consistent with national reporting (Larned et al. 2015).

Overall, these changes have had the effect that the parameters for which a significant trend has been reported have changed. A comparison between the results of the confidence grading system and the previous p-value based significance method is also given in Appendix V. This analysis shows that the confidence based system identifies the same trends as the significance based system, when the statistical output is interpreted correctly. A further analysis is provided in the table below, identifying the changes in reported trends compared to previous reporting periods where the p-value of the f-statistic was incorrectly reported. This shows that between the two periods there are few similarities in reported trends, with only chlorophyll-a at all sites, TLI at site L2 and total phosphorus for the whole lake showing increasing trends in both analyses. Previous reporting did not detect any decreasing trends, which is due to the interpretation of trends in previous years. It should also be noted that the parameters used in the trend analysis have changed slightly, with turbidity now included in the analysis and suspended solids, dissolved oxygen and temperature no longer trended.

Comparison of trends reported in the 2018-2019 using previous methodology and interpretation with trends reported in the current period using updated methodology

Parameter	Site	Previous Reporting			Current Reporting			
		p-value	R	Trend Categorisation	Median Sen Slop	Percent Annual Change	Trend Category	Confidence (%)
CHLA	L2	0.02	0.23	Significant Deterioration	0.00005	1.79	Very Likely Degrading	99.60
	L3	0.04	0.20	Significant Deterioration	0.00004	1.70	Very Likely Degrading	99.50
	Whole Lake	0.002	0.21	Highly Significant Deterioration	0.00006	2.06	Very Likely Degrading	99.94
COND	L2	0.66	0.03		0.27599	0.23	Likely Degrading	89.03
	L3	0.31	0.08		0.37984	0.32	Very Likely Degrading	98.65
	Whole Lake	0.33	0.05		0.31594	0.27	Very Likely Degrading	98.68
DRP	L2	0.49	0.06		0.00000	0.00	Indeterminate	55.05
	L3	0.48	-0.06		0.00000	0.00	Very Likely Improving	92.27
	Whole Lake	0.98	-0.00		0.00000	0.00	Indeterminate	61.16
NH4	L2	0.84	-0.02		0.00000	0.00	Indeterminate	50.00
	L3	0.83	0.02		-0.00027	-2.48	Very Likely Improving	98.46
	Whole Lake	0.98	-0.00		-0.00015	-0.85	Likely Improving	79.33
NNN	L2	0.0008	0.29	Highly Significant Deterioration	-0.00138	-0.37	Likely Improving	78.25
	L3	0.0008	0.29	Highly Significant Deterioration	0.00000	0.00	Indeterminate	51.06
	Whole Lake	0.000002	0.29	Highly Significant Deterioration	-0.00066	-0.17	Indeterminate	62.44
SECCHI	L2	0.98	-0.00		-0.00892	-0.33	Likely Improving	73.59

Parameter	Site	Previous Reporting			Current Reporting			
		p-value	R	Trend Categorisation	Median Sen Slop	Percent Annual Change	Trend Category	Confidence (%)
	L3	0.36	-0.09		-0.00767	-0.25	Likely Improving	76.58
	Whole Lake	0.48	-0.05		-0.00333	-0.11	Indeterminate	61.04
TN	L2	0.58	0.05		-0.00500	-0.80	Very Likely Improving	98.80
	L3	0.94	-0.01		-0.00495	-0.81	Very Likely Improving	98.94
	Whole Lake	0.75	0.02		-0.00500	-0.80	Very Likely Improving	99.53
TP	L2	0.09	0.15		0.00057	2.31	Very Likely Degrading	99.99
	L3	0.17	0.13		0.00016	0.84	Very Likely Degrading	93.30
	Whole Lake	0.03	0.14	Significant Deterioration	0.00041	1.79	Very Likely Degrading	99.86
TURB	L2	Not analysed			0.02227	0.97	Very Likely Degrading	94.79
	L3	Not analysed			0.00909	0.61	Likely Degrading	86.41
	Whole Lake	Not analysed			0.01484	0.82	Very Likely Degrading	93.11
TLI	L2	0.03	0.20	Significant Deterioration	0.01047	0.25	Very Likely Degrading	95.59
	L3	0.01	0.26	Significant Deterioration	0.01204	0.29	Very Likely Degrading	91.59
	Whole Lake	0.009	0.24	Highly Significant Deterioration	0.01342	0.32	Very Likely Degrading	93.55